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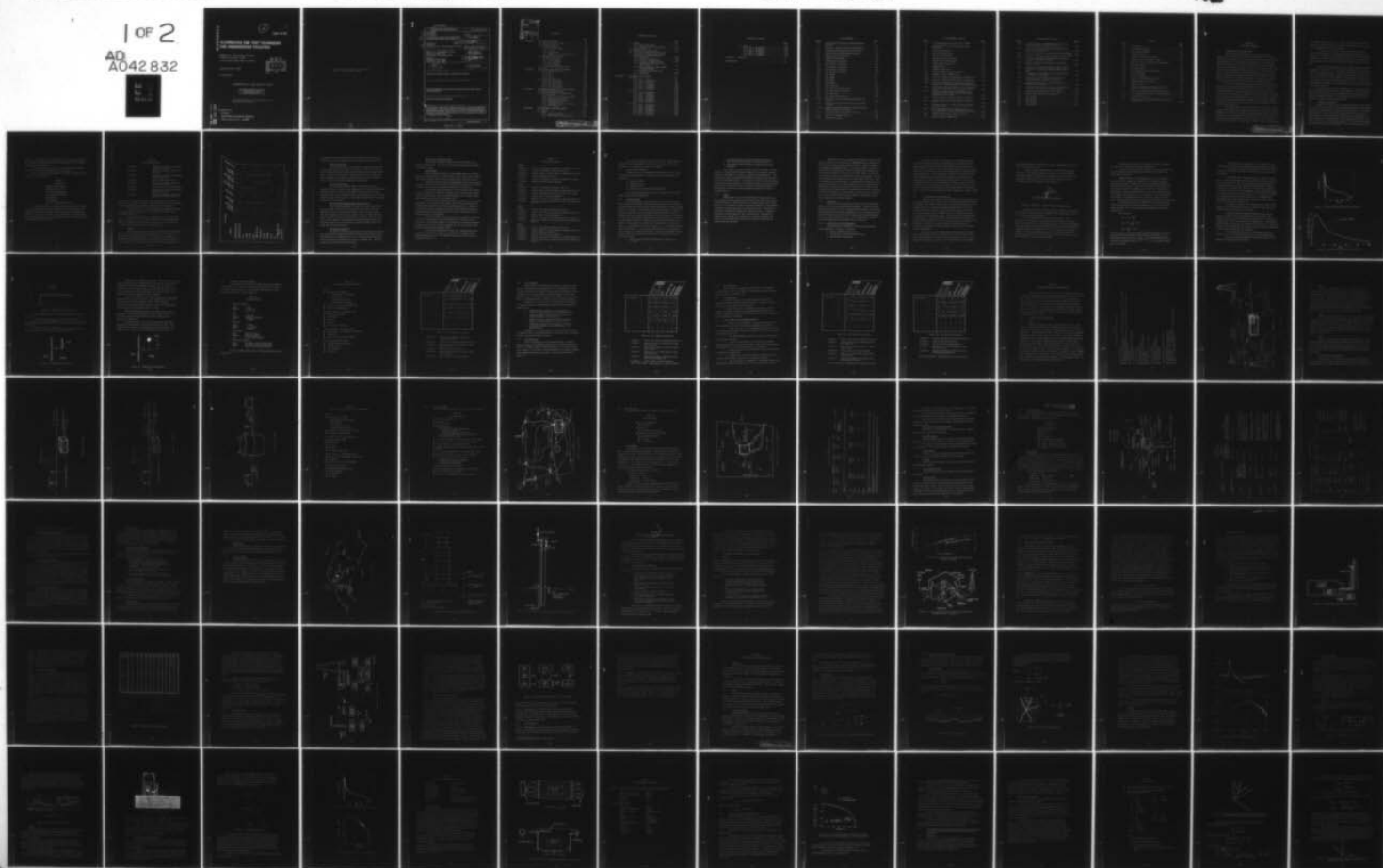
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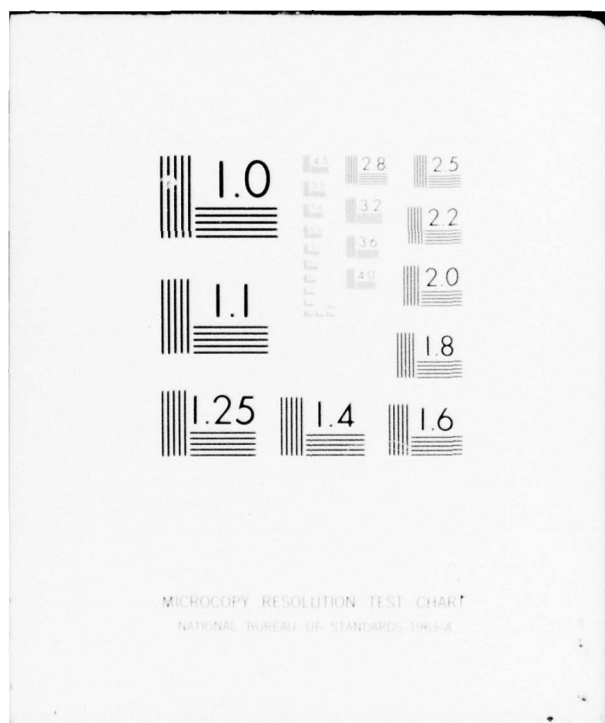
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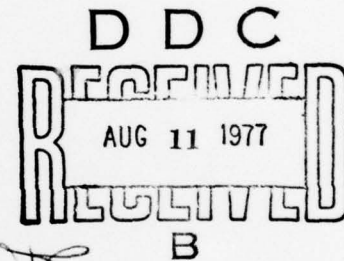
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## ALTERNATIVE EMP TEST TECHNIQUES FOR UNDERGROUND FACILITIES

EG&G, Inc., Albuquerque Division  
9733 Coors Road, N.W.  
Albuquerque, New Mexico 87114

20 September 1976

Final Report



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ABSTRACT (Continue on reverse side if necessary and identify by block number) This document contains the results of a study to evaluate the applicability and usefulness of the various EMP test techniques on underground communications facilities. Four classes of sites are defined which typify the majority of buried facilities and a mix of test and analysis techniques is evaluated for each class.		

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## SECTION 1

### EXECUTIVE SUMMARY

#### 1.1 BACKGROUND AND OBJECTIVES

EG&G, under contract to DNA, has undertaken to perform a definitive tradeoff analysis of Electromagnetic Pulse (EMP) test techniques which might be employed in the assessment of underground Command, Control, and Communication (C<sup>3</sup>) facilities for survivability in a high altitude EMP environment. Four classes of potential buried C<sup>3</sup> facilities were defined. These four classes bound, or typify, the majority of the facilities which would be encountered in the DNA C<sup>3</sup> Assessment Program. For each of the four classes, an optimum mix of test and analysis techniques has been defined. This document is a final report on this evaluation study and defines the four classes, identifies the four typical actual sites, presents the test technique evaluation criteria, and the conclusions and recommendations derived.

The Defense Nuclear Agency is currently conducting comprehensive programs to assess the high altitude EMP vulnerability of C<sup>3</sup> systems. This program includes evaluation of many types of voice, teletype, and digital communication links. Because of the diversity and scope of this program, a large variety of structural types of buildings will be encountered. This includes, but is not limited to, buildings which are buried or on the surface, buildings which are unshielded or well shielded, buildings which incorporate hardened penetrations, and buildings with very simple or very complicated external and internal coupling geometries.

The primary thrust of the DNA C<sup>3</sup> Programs is analytical, depending primarily upon computerized modeling techniques such as the Boeing developed PRESTO code. However, to validate computerized models and to verify their predictions, some form of EMP testing is required. Test techniques can vary from simple low-level CW direct injection of signals on cables up through threat level pulse radiation. A large variety of EMP test devices and simulators

are available to perform these tests. Hence, trade studies are required to determine the optimum mix of test techniques and simulators for the various classes of buried facilities to be encountered.

The objective of this study is to perform a definitive tradeoff analysis of the alternative test and simulation techniques available for determining the survivability of certain classes of buried  $C^3$  facilities for an EMP environment. Several buried  $C^3$  systems may require testing for EMP vulnerability and such a trade study would be helpful in planning for future specific tests.

This study has not attempted to define a single preferred technique for each site. A decision to test, and subsequent experiment design is highly individual for each test program, and depends upon many time varying parameters. Such parameters include simulation state-of-the-art, analysis state-of-the-art, the role a site has in support of national priorities, available funds, etc. Because of the highly flexible natures of these factors, it is impossible to determine far in advance an optimum technique; this depends on test objectives and available resources.

This study scrutinized many combinations of test analysis methods and evaluated them in terms of accuracy, applicability, cost, and other factors. Thus, for several classes of sites, including most actual existing buried  $C^3$  facilities, optimum combinations of test and analysis methods can be chosen in light of test objectives and program priorities.

## 1.2 TECHNICAL APPROACH

Because of the large variety of potential configurations which buried  $C^3$  sites might assume, EG&G has taken an approach which allowed the majority of these sites to be bounded by a sample of four generalized sites. Each of the four generic sites is discussed in more detail in Section 2 of this document. Briefly the four sites are typified by the following measured parameters, (1) a large complex site with many buildings -- some buried, some shielded, some both, some neither, (2) site buried and shielded, (3) site buried but unshielded, and (4) single tall structure partially buried. For each of the four classes of

facilities, an actual specific site representative of the class has been selected for an example. Detailed descriptions of the four actual sites are contained in Section 2 of this document.

For each of the four actual sites, the applicability and usefulness of various test techniques and simulators will be evaluated.

The seven test methods typically used in EMP vulnerability assessments are shown in Table 1-1.

Table 1-1  
Test Methods

POE Direct Drive (Pulse)  
POE Direct Drive (CW)  
High Level Pulse Radiation  
Low Level Pulse Radiation  
CW Radiation  
Scale Modeling  
Subsystem ("Black Box") Testing

Inasmuch as these test methods are almost always used in combination to form an integrated assessment program, the test methods have been grouped together in eight groupings. We have assigned the name assessment technique to each group. Each assessment technique then is a combination of the test methods plus analysis. The combinations that were used in this evaluation program are shown in Table 1-2.

Table 1-2  
Assessment Techniques

Technique 1	Analysis; Scale Modeling; Subsystem ("Black Box") Testing
Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High-Level Pulse Radiation; POE Direct Drive (P)
Technique 4	Analysis; POE Direct Drive (P)
Technique 5	Analysis; CW Radiation; Subsystem ("Black Box") Testing
Technique 6	Analysis; High-Level Pulse Radiation
Technique 7	Analysis; Low-Level Pulse Radiation; POE Direct Drive (P)
Technique 8	Analysis; CW Radiation; POE Direct Drive (CW); POE Direct Drive (P)

Combinations of the above methods have been employed in many of the major EMP programs completed in the past. Application of the assessment techniques in the past EMP programs is illustrated in matrix form in Figure 1-1.

Brief explanations of each of the individual test techniques are contained in the following paragraphs. A more detailed description of each is contained in Section 3.

These are the individual test methods used in any assessment program. A test method is rarely, if ever, employed in an isolated application. Rather, a combination of test methods are chosen to arrive at an integrated assessment program or technique for a particular site.

#### Analysis

Analysis will mean those analytical and predictive methods used to relate test data to phenomenology and for extrapolation to threat levels. Since the primary analytical tool of the DNA C<sup>3</sup> EMP assessment is PRESTO, it is assumed that the coupling predictions will be generated using the PRESTO code or some equivalent code whose accuracy is well known for these applications.



For subsequent evaluations herein (such as cost estimates) analysis will also include the off-site data reduction processes required in each particular case.

#### POE Direct Drive (P)

The pulse direct drive of facility POEs is a method often employed to augment illumination of the facility by radiating or bounded wave simulation. Due to insufficient coupling the latter methods inadequately or improperly drive POEs. An example of this would of course be long aerial lines. Pulse Direct Drive is therefore often employed to provide these time domain simulations and/or to extend to threat levels and facility nonlinearities.

#### POE Direct Drive (CW)

The direct drive of facility POEs in the frequency domain is employed for reasons similar to those of pulse drive, that is direct measurement of transfer functions. However, this method would not normally be used to threat levels, but rather to extend the dynamic measurement range for obtaining transfer functions of linear systems. This method is frequently used to measure parameters to aid in analysis.

#### Pulse Radiating Simulation (High- and Low-Level)

Pulse radiating simulators are employed for assessment of direct energy penetration into facilities and excitation of some POEs. They have advantage in efficiency of assessment by virtue of their time domain nature. They differ in peak field levels (from as little as 1 kV/m to full threat levels), spectral content, polarization, and uniformity of excitation. Therefore, selection of a pulse simulator is determined by the particular facility to be tested. The pulse simulators to be considered in this study are TEMPS, RES-I, and SIEGE type underground excitation.

#### CW Radiating Simulators

The methods employed by these single or swept frequency simulators have their principal advantage in the extended dynamic range of measurement. Peak field levels are comparatively very low. Has utility in obtaining system transfer functions and to identify flaws ("leaks") is shielded sites. CW drive bounded arrays offer further increased range.

#### Subsystem or "Black Box" Tests

This method is employed in instances when facility POEs can not be driven to threat levels. It is used to determine upset and damage thresholds and margins of safety.

#### Scale Modeling

While not commonly employed, Scale Modeling offers an alternative approach to complex facilities; to instances where analysis and analytical models offer limited confidence and may not be possible because of practical reasons.

Inasmuch as there are numerous permutations of the eight assessment techniques, preliminary screening based on engineering judgement and experience was performed to arrive at a reasonable minimum set of combinations.

Based upon the four representative sites, the foregoing test methods have been grouped into combinations of methods, each combination thus forming an assessment technique. Eight assessment techniques were considered applicable and sufficient for all four representative sites.

Clearly the use of an arbitrary number of permutations of all possible combinations of test methods is not feasible. The result would expand the subsequent technique evaluation task beyond manageable proportions. Therefore, for each site evaluation, techniques were based not only upon the particular site characteristics but also upon that which was reasonable, and thus necessarily contain an element of subjectiveness.

At the other extreme, there has been the strong tendency to prejudge as to the one single suitable assessment technique at the exclusion of all or many others. Avoiding this tendency, a reasonable set of assessment techniques has been chosen for each site and the judgement as to the most suitable will be determined by subsequent evaluation criteria.

For each of the individual four actual sites, additional preliminary screening was performed to arrive at a reasonable set of techniques which could be applied to that site. The techniques chosen for the various sites are illustrated in Table 1-3.

Table 1-3  
Assessment Techniques

SITE 1

Technique 1	Analysis; Scale Modeling; Subsystem ("Black Box") Testing
Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High-Level Pulse Radiation; POE Direct Drive (P)
Technique 4	Analysis; POE Direct Drive (P)
Technique 5	Analysis; CW Radiation; Subsystem ("Black Box") Testing
Technique 6	Analysis; High-Level Pulse Radiation

SITE 2

Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High-Level Pulse Radiation; POE Direct Drive (P)
Technique 5	Analysis; CW Radiation; Subsystem ("Black Box") Testing
Technique 6	Analysis; High Level Pulse Radiation
Technique 7	Analysis; Low-Level Pulse Radiation; POE Direct Drive (P)
Technique 8	Analysis; CW Radiation; POE Direct Drive (CW); POE Direct Drive (P)

SITE 3

Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High-Level Pulse Radiation; POE Direct Drive (P)
Technique 6	Analysis; High Level Pulse Radiation
Technique 7	Analysis; Low-Level Pulse Radiation; POE Direct Drive (P)
Technique 8	Analysis; CW Radiation; POE Direct Drive (CW); POE Direct Drive (P)

SITE 4

Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High-Level Pulse Radiation; POE Direct Drive (P)
Technique 4	Analysis; POE Direct Drive (P)
Technique 6	Analysis; High Level Pulse Radiation
Technique 7	Analysis; Low-Level Pulse Radiation; POE Direct Drive (P)
Technique 8	Analysis; CW Radiation; POE Direct Drive (CW); POE Direct Drive (P)

For each site and for each grouping of techniques, a final evaluation to determine the optimum analysis/test mix was performed. For the final evaluation, a set of evaluation criteria were developed.

### 1.3 EVALUATION CRITERIA

In order to assess the applicability and desirability of using a given test and/or simulation technique, the following evaluation criteria have been established.

1. Accuracy of Data
2. Approximate Cost
3. Duration of Test
4. Interference with Routine Facility Operation

The meaning and application of the above evaluation criteria will be discussed in the following paragraphs.

#### 1.3.1 Accuracy of Data

The amount and type of data required of a test program is dictated by the confidence requirements of the assessment program, and the confidence interval provided by the analysis portion of the program along with data provided by other test techniques. For instance, should a high confidence assessment be desired in conjunction with a low confidence analytical technique, then large volumes of extremely accurate high quality data would be required. Conversely, if an extensive, high confidence analytical assessment program is utilized then less data would be required to validate portions of the analytical model. For purposes of this program, data quality has been divided into three categories, high, i. e., error bounds of less than 6 dB; medium, i. e., error bounds between 6 and 20 dB; and low, i. e., error bounds within 20 to 40 dB. Error bounds in excess of 40 dB are considered unacceptable. Achievable data qualities for the potential simulation and measurement techniques to be utilized in a test were assessed based upon:

1. Direct historical evidence of data taken on similar site or test items.

2. Based upon experienced and demonstrated reliability of a known measurement technique or measurement devices.
3. Based upon estimated reliability of required measurement techniques.

The accuracy of analytic techniques were also evaluated. For this study it was assumed that the analysis techniques to be considered would have accuracies comparable to the predictive capability of the PRESTO code. This code has been used to develop EMP and TEMPS environment response predictions at two AUTOVON facilities. Comparison of test data to pretest predictions has been performed to determine, in a quantitative fashion, the accuracy of the predictions as a function of the level of complexity of the coupling path to the point at which the prediction and the subsequent measurement were made, (see Reference 1).

#### 1.3.2 Costs

SIMULATORS — Each of the potential EMP simulators that have been evaluated in this program have been examined to determine their approximate operating costs. Simulators in this sense applies to pulse and CW cable drivers, low level radiators as well as threat level simulators. Each has been evaluated to determine such factors as transportation costs, setup and tear-down times, and manpower requirements, operating costs (i.e., number of personnel and material required), data acquisition costs, and finally data reduction costs. Whenever two simulators or two types of simulation will satisfy a test requirement, the less expensive simulator has been the one which has been recommended.

ANALYSIS — It has been assumed for the purpose of this study, that analysis techniques will be based upon the PRESTO prediction modeling code which has been employed and developed by the Boeing Company in support of the PREMPT and APACHE Programs. No attempt is made, or intended, to provide actual or reasonable cost for any of the analytical assessments to be encountered in the DNA's C<sup>3</sup> Assessment Programs. Rather a relative cost in rank orders for the various analysis efforts has been developed. There are many assumptions and ground rules in this costing effort which may, or may not, hold during an actual assessment. In determining the relative cost of an analytical assessment, the size and complexity of the site combined with the availability of test data will be primary consideration, for instance a fairly simple facility with limited numbers of penetrations which was to be subjected to a full scale simulation test would require very little in the way of analysis. For this type of facility and this type of technique an "abbreviated" analytic assessment would be considered adequate.

#### 1.3.3 Practicality

Each of the test and simulation techniques has been evaluated and ranked in terms of the practicality of instrumentation. Those factors which influence the practicality of a test technique include such things as the number of independent agencies requiring coordination, the size and complexity of the physical facilities required, the logistics requirements and their availability, site access topology and location, (e. g., use of a TEMPS type simulator on steep rocky mountainous terrain would not be recommended).

#### 1.3.4 Interference with Normal Operation

The potential forms of interference with routine operation have been grouped in three categories. These are:

1. physical modifications to the site,
2. interruptions of site functional activity, and
3. Special safety considerations.

In the first category, each simulation or test technique has been evaluated and ranked according to those modification requirements attendant upon use of that simulator. There are then three classes of modification. The first of these is moderate which would include limited earth work, limited temporary site modification, such as disconnecting cables, or installing special measurement devices. The second category, which is more severe in nature, would include potentially large earth work, expensive or more permanent modifications to the site for instance cutting holes in doors or walls to route instrumentation cables or transmission links, and finally temporary installation of additional office or laboratory space in the form of vans or trailers. The final category of physical modifications would include facilities construction on site as grading, clearing, installation of footings, parking lots, sanitary facilities, etc.

#### 1.4 ELECTROMAGNETIC APPROACH

EG&G has engaged the services of the Mission Research Corporation to provide additional analytic support in the area of Electromagnetic Propagation and Coupling. Using MRC computer codes, the incident and subsurface electromagnetic fields for an assumed high altitude (HA) EMP and for each of the simulators have been computed. Thus, the subsurface fields generated by the various simulators can be compared to those of a HA EMP to determine the adequacy of the simulation technique, and the amount of extrapolation which would be required. For the simulators a crude approximation of the type of signals to be anticipated for each of the four specific sites was calculated. The usefulness of each of the simulators can then be evaluated in terms of: 1) adequacy of simulation, 2) ability to generate sufficient response to fulfill the data requirements.

The various external coupling paths have been modeled. The purpose of this modeling effort was to determine the relative currents induced on these coupling paths by an assumed HA EMP and each of the various radiating simulators. Of particular concern in any radiated EMP tests is the ability of

this radiating simulator to adequately excite long coupling paths such as power lines or communication cables.

HIGH ALTITUDE EMP ANALYSIS — The HA field is defined in Reference 2. Two worst case studies were made. Case I maximized the horizontally polarized component of the incident electric field. This occurs at an angle of incidence of  $26^\circ$  from the vertical, with an electric field polarization angle of  $79^\circ$  from the vertical (Figure 1-2).

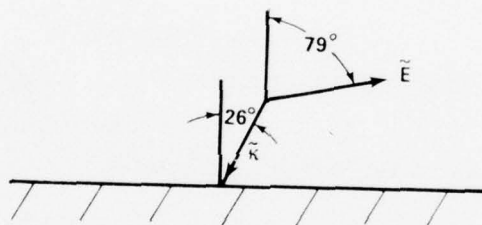


Figure 1-2. HA Case I - Angles of Incidence and Polarization

Case II maximized the vertically polarized component of the incident electric field. This is at an angle of incidence of  $26^\circ$  and polarization angle of  $70^\circ$ , with the angles defined as before.

The HA field is uniform everywhere at the surface. The effect of ground parameters on the reflection and transmission of the fields by the ground need only to be calculated at one point. The incident and reflected electric and magnetic fields were calculated at the surface of the ground and the transmitted fields were calculated at 1, 5, 10, 15, and 20 meters below the surface. The effect of soil water contents of 1, 10, and 50 percent were calculated on these fields; the 10 percent water content is an average soil, and the 1 and 50 percent cases are used as bounds.

Conductivity and sensitivity are obtained as functions of frequency according to the methodology of Longmire (Reference 3).

The plane wave reflection and transmission coefficients (Reference 4) for vertical and horizontal polarizations were used to get the fields at the surface and in the ground.

TEMPS ANALYSIS — The TEMPS analysis is more complicated than that of the HA, because the TEMPS fields are a function of position. To simplify the analysis, TEMPS is assumed to be infinitely long and at its maximum height (20 meters). The electric and magnetic fields were derived from measured output of the TEMPS given in Figure 1-3. The fields were calculated for a square extending 100 meters in each direction from the center of the TEMPS, at 50 meter increments. The incident, reflected, and transmitted fields were calculated for the same depths in the ground as the HA fields. Only the fields for soil water contents of 1 and 10 percent were calculated.

The analytical model for the TEMPS field was necessarily simple, and was based on theory for an antenna infinitely long. The expressions of Jordon (Reference 5) for a finite antenna were expanded to give the infinite antenna result.

The results are:

$$E_z = -\frac{1}{\psi} \frac{V_o(t)}{R_o}$$

$$E_y = \frac{1}{\psi} \frac{z}{y R_o} V_o(t)$$

$$H_\phi = \frac{1}{\psi Z_o y} V_o(t) \quad ,$$

where  $E_z$  and  $E_y$  are the electric fields longitudinal and radial to the antenna, respectively,  $H_\phi$  is the magnetic field azimuthal to the antenna,  $y$  is the perpendicular distance from the antenna,  $z$  is the longitudinal distance from the center of the antenna, and  $R_o = \sqrt{y^2 + z^2}$ .  $V_o(t)$  is the pulser voltage, and  $\psi$  is a constant.

These equations were normalized to give a peak electric field of 50 KV/m at 50 meters from the antenna having the waveshape of Figure 1-3.

The fields in the ground were calculated using the same reflection coefficients (which depend upon angle of incidence) as were used for the HA calculations.

**SIEGE ANALYSIS** — The SIEGE fields are a function of position also. For this study the SIEGE array was assumed to be 3 meters above the ground, and 110 meters long. The total electric and magnetic fields are calculated beneath the simulator at the same depths as before at various locations along the length of the simulator. The ground has a conductivity of 0.01 mhos/meter and a relative permittivity of 100, which approximately corresponds to a soil water content of 10 percent. The fields are calculated for two different pulsers exciting the SIEGE; one is a standard double-exponential pulser, whose output is shown in Figure 1-4, and the other is a step function pulser shown in Figure 1-5.

The method of solution is a two-dimensional time domain finite difference solution of Maxwell's equations. Neither the source end nor the load end of the above ground array was loaded.

**OVERHEAD CABLE CURRENTS ANALYSIS** — The currents induced on a cable by the HA and TEMPS fields were calculated. The cable was defined as a 1-3/4" OD power line cable with an 1/8" thickness of insulation with a relative permittivity of 2.75 (polyethylene). Two lengths, 50 and 100 meters were studied. The cables were 10 meters above a ground with 10 percent water content, and were shorted to earth on each end by an additional length of the cable extending to the ground level.

For HA excitation, the worst case of broadside incidence was calculated, i.e., the entire length of the cable is excited simultaneously.

The cable is excited by both the incident and reflected (from the earth) waves with appropriate time delays.

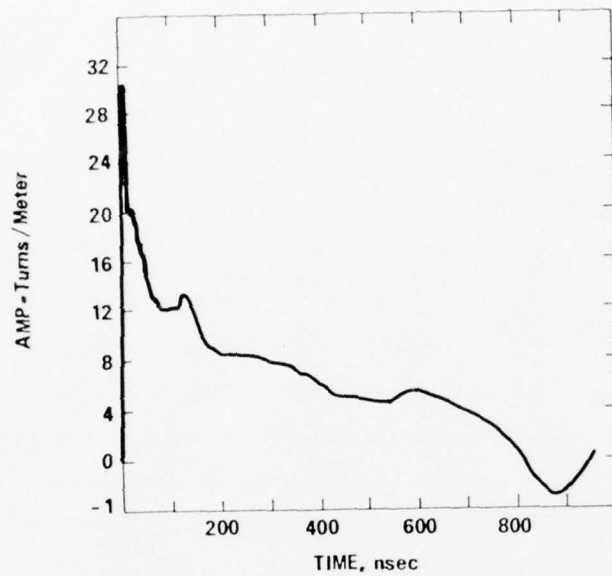


Figure 1-3. TEMPS Tangential Magnetic Field at 50 Meters

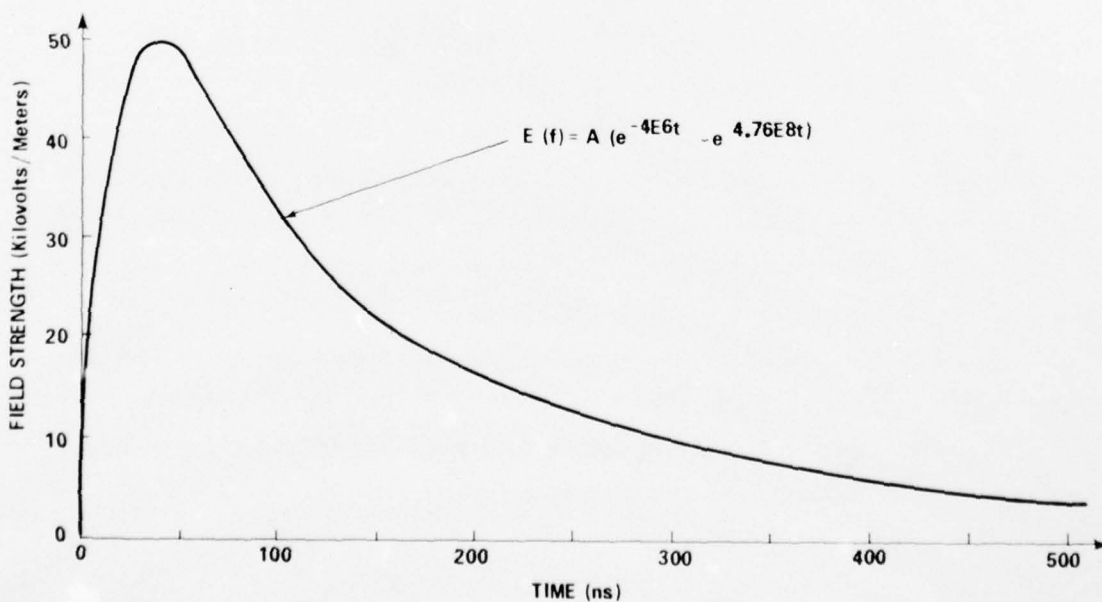


Figure 1-4. SIEGE Double Exponential Pulse Excitation

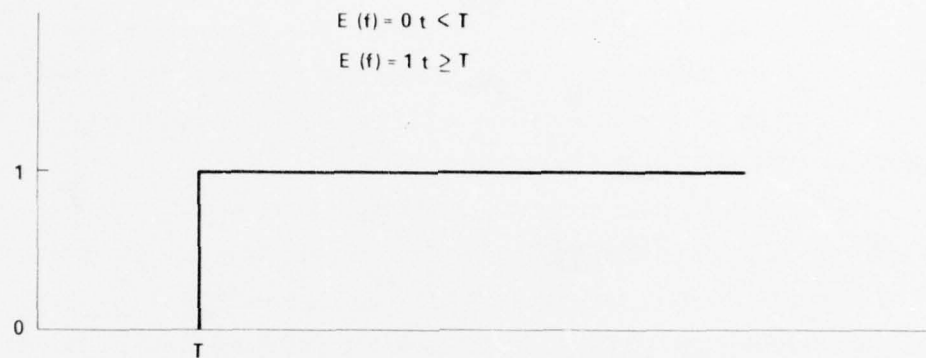


Figure 1-5. SIEGE Step Function Excitation

For the TEMPS excitation, the cable was orientated as shown in Figure 1-6.

The cable is again excited by the incident and reflected waves, and the spatial variation of the TEMPS fields is taken into account, including time delays.

The cable solutions are obtained by using a time domain finite difference solution to the telegrapher's equations (Reference 6).

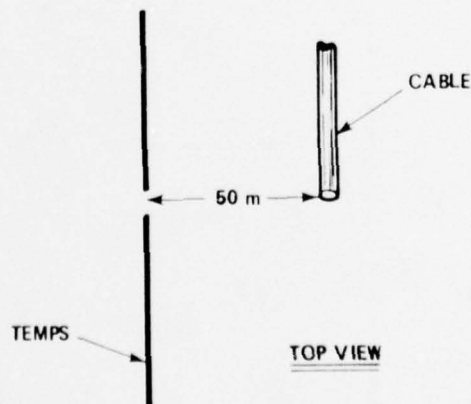


Figure 1-6. TEMPS Cable Orientation

BURIED CABLE CURRENTS ANALYSIS -- The short circuit currents induced on cables buried 1 and 5 meters below the surface of the ground were calculated for both the HA and TEMPS excitation. The same cable type which was used in the overhead cable currents analysis was used, as well as the same cable lengths. The ground had a 10 percent water content. The cables had the same orientation as for those overhead.

The method of solution is that of Wilson (Reference 7) which treats the buried cable as a transmission line. The incident fields are those transmitted into the earth to the appropriate depth. The HA fields are incident everywhere along the cable uniformly, where as the TEMPS fields are non-uniform in both amplitude and time of arrival

TOWER CURRENTS ANALYSIS -- The short circuit currents induced on a tower 80 meters high with an average radius of 7 meters were calculated for both the HA and TEMPS excitation by using handbook information of Reference 8.

The voltage induced on the tower was calculated analytically by integrating the incident electric field along the height of the tower. This voltage is used with Figure 2-14 of Reference 3 to give the currents. The TEMPS induced currents are for the configuration shown in Figure 1-7.

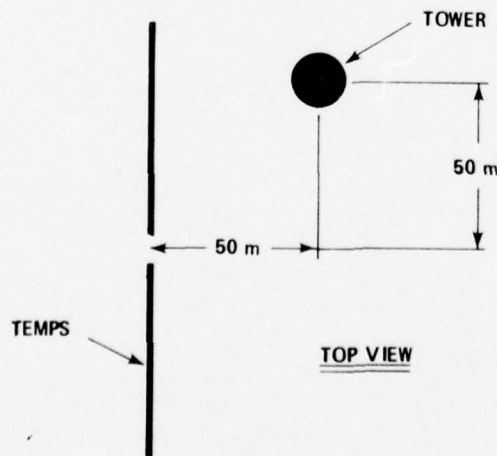


Figure 1-7. TEMPS Tower Configuration

## 1.5 SUMMARY AND CONCLUSIONS

In this Section we will present, in summary form, the results of the evaluations. For each site, a matrix summarizes the results in terms of each of the evaluation criteria. For simplicity, each criterion has been divided into categories as shown in Table 1-4.

Table 1-4  
Evaluation Factors

1. Accuracy of Data:

High	$\leq 6$ dB
Medium	$6 < \text{dB} \leq 20$
Low	$20 < \text{dB} \leq 40$
2. Cost:

High	$> \$500,000$
Medium	$\$100,000 - \$500,000$
Low	$< \$100,000$
3. Duration:

Short	$> 3$ months
Medium	$3 - 6$ months
Long	$> 6$ months
4. Practicality:

High	Quick and simple
Medium	Moderately difficult
Low	Large complex program
5. Interference with Site:

High	Possibility of long transient upset
Medium	Possibility of short transient upset
Low	Require site personnel assistance

An overview of the characteristics of the four actual sites is given in Table 1-5.

Table 1-5  
Overview of the Four Sites Chosen

- I. Site 1
  - Most Diversity of POEs
    - Buried Cables/VLF Antennas
    - HF Antennas
    - Two Microwave Towers
    - Satellite Ground Terminal
  - Large Size: Greater than 1 km square
  - Designed for EMP Hardness
- II. Ellisville, Florida. Ground Entry Point
  - Simplest Site Possible
  - One Building
  - No Tower
  - Shielded
  - Few Antennas and Cables
- III. Lamar, Colorado. Ground Entry Point
  - More Typical, in the Middle of the Spectrum
  - Unshielded
  - Microwave Tower 75' from Building
- IV. Site 4 Communications Station
  - Partially Buried Tall Structure
  - Partially Shielded
  - Blast Hardened
  - Few POEs

		ASSESSMENT CONFIDENCE			COSTS	DURATION OF TEST	PRACTICALITY	INTERFERENCE WITH FACILITY
		ACCURACY TEST DATA	EXTRAPOLATION ACCURACY					
TECHNIQUE	1	Hi	Med	Med	Med	Hi	Lo	
	2	Hi	Med	Med	Med	Hi	Med	
	3	Lo	Med	Hi	Long	Lo	Med	
	4	Hi	Med	Lo	Short	Hi	Med	
	5	Hi	Med	Lo	Short	Hi	Lo	
	6	Lo	Lo	Hi	Long	Lo	Lo	

Figure 1-8. Site 1 Results of Evaluation

Technique 1	Analysis; Scale Modeling; Subsystem ("Black Box") Testing
Technique 2	Analysis; CW Radiation; POE Direct Drive (P)
Technique 3	Analysis; High Level Pulse Radiation; POE Direct Drive (P)
Technique 4	Analysis; POE Direct Drive (P)
Technique 5	Analysis; CW Radiation; Subsystem ("Black Box") Testing
Technique 6	Analysis; High Level Pulse Radiation

#### 1.5.1 Site 1 Summary

Because Site 1 is well shielded and hardened, typical assessment type tests using high level radiated pulsing is not recommended; this places Techniques 3 and 6 on the bottom of the rank ordering of techniques for Site 1, see Figure 1-8. The most confidence per dollar expended is gained using Techniques 4 and 5. Technique 2 follows closely behind 4 and 5. One of these three, or a combination thereof, would seem to be the preferred approach.

Because Site 1 is not yet built, it would be extremely advantageous to incorporate built in test capability design trade studies recommended to evaluate use of:

1. POE Direct Drive attachments such as pigtailed or toroids with assessable above ground attachment points.
2. Buried coils which could be driven in the CW mode to monitor shielding as a function of time.
3. Means of injecting currents directly onto the walls of building to monitor shielding as a function of time.
4. Installation of permanent current probes at the inside and outside of POEs to monitor POE hardness as a function of time.

In addition, it is recommended that CW EMI/EMC type testing of the building shielding be accomplished during construction, before the building is buried, and after the building is buried.

#### 1.5.2 Site 2 Summary

At Site 2, Technique 5 is the preferred technique. It provides medium accuracy when extrapolated and has the least interference with site activity. Techniques 2 and 8 are ranked just below 5. They provide slightly more confidence, but introduce a non-zero probability of site upset or damage during POE threat level pulse direct drive. These results are shown in Figure 1-9.

		ASSESSMENT CONFIDENCE			COSTS	DURATION OF TEST	PRACTICALITY	INTERFERENCE WITH FACILITY
		ACCURACY TEST DATA	EXTRAPOLATION ACCURACY					
TECHNIQUE	2	Hi	Med	Lo	Short	Hi	Med	
	3	Hi	Med	Hi	Med	Lo	Hi	
	5	Hi	Med	Lo	Med	Hi	Lo	
	7	Hi	Lo	Hi	Med	Lo	Med	
	8	Hi	Med	Lo	Med	Hi	Med	
	6	Hi	? <sup>(1)</sup>	Hi	Med	Lo	Hi	

Figure 1-9. Site 2 Results of Evaluation

- Technique 2      Analysis; CW Radiation; POE Direct Drive (P)
- Technique 3      Analysis; High Level Pulse Radiation; POE Direct Drive (P)
- Technique 5      Analysis; CW Radiation; Subsystem ("Black Box") Testing
- Technique 7      Analysis; Low Level Pulse Radiation; POE Direct Drive (P)
- Technique 8      Analysis; CW Radiation; POE Direct Drive (CW) POE Direct Drive (P)
- Technique 6      Analysis; High Level Pulse Radiation

Note (1) Questionable - Additional tests or analysis required

#### 1.5.3 Site 3 Summary

The results on the technique evaluation at Site 3 are similar to those from Site 2. That is, Technique 5 is the preferred technique followed closely by 2 and 8, see Figure 1-10.

#### 1.5.4 Site 4 Summary

Technique 7 utilizing the vertically polarized airborne RES simulator provides the highest confidence assessment. However, it scores poorly in cost, practicality and site interference.

The three other techniques evaluated for potential use at Site 4 appear to be equally desirable. It is recommended that the particular test methods employed in a test of this type of site be based on other considerations such as availability of equipment.

### 1.6 CONCLUSIONS AND RECOMMENDATIONS

1. High or low level radiation test, either CW or pulse, is not recommended for sites with  $\geq 80$  dB shielding and hardened penetrations.

2. Built in test devices, such as POE direct drive points, should be incorporated in new buried shielded and hardened sites to monitor hardness of site during its life cycle.

3. New shielded buildings should be tested during construction to verify integrity of shields.

4. Any final decision on the use of the various test methods depends strongly on the test objectives, and the results of this study should be re-evaluated when a test of any particular site is contemplated.

5. Additional studies are recommended on Site 1 design tradeoffs for EMP self test capabilities.

6. Buildings with questionable shielding should have low level testing or analysis prior to high level test to determine feasibility.

7. This study pertains to HAEMP only. Additional studies should be performed to optimize testing mixes for close-in ground burst coupling.

		ASSESSMENT CONFIDENCE			COSTS	DURATION OF TEST	PRACTICALITY	INTERFERENCE WITH FACILITY
		ACCURACY TEST DATA	EXTRAPOLATION ACCURACY					
TECHNIQUE	2	Hi	Med	Lo	Short	Hi	Med	
	3	Hi	Med	Lo	Short	Hi	Lo	
	5	Hi	Med	Lo	Short	Hi	Lo	
	6	Hi	? (1)	Hi	Med	Lo	Hi	
	7	Hi	Med	Med	Short	Hi	Med	
	8	Hi	Med	Lo	Med	Lo	Hi	

Figure 1-10. Site 3 Results of Evaluation

Technique 2      Analysis; CW Radiation; POE Direct Drive (P)

Technique 3      Analysis; High Level Pulse Radiation POE  
Direct Drive (P)

Technique 5      Analysis; CW Radiation; Subsystem ("Black  
Box") Testing

Technique 6      Analysis; High Level Pulse Radiation

Technique 7      Analysis; Low Level Pulse Radiation POE  
Direct Drive (P)

Technique 8      Analysis; CW Radiation; Poe Direct Drive  
(CW) POE Direct Drive (P)

Note (1) Questionable - Additional tests or analysis required

		ASSESSMENT CONFIDENCE					
		ACCURACY TEST DATA	EXTRAPOLATION ACCURACY	COSTS	DURATION OF TEST	PRACTICALITY	INTERFERENCE WITH FACILITY
TECHNIQUE	2	Hi	Med	Lo	Short	Hi	Med
	4	Hi	Med	Lo	Short	Hi	Med
	6	Hi	? <sup>(1)</sup>	Hi	Med	Lo	Hi
	7	Hi	Hi	Hi	Med	Lo	Hi
	8	Hi	Med	Lo	Short	Hi	Med

Figure 1-11. Site 4 Results of Evaluation

Technique 2      Analysis; CW Radiation; POE Direct Drive (P)

Technique 4      Analysis; POE Direct Drive (P)

Technique 6      Analysis; High Level Pulse Radiation

Technique 7      Analysis; Low Level Pulse Radiation; POE  
Direct Drive (P)

Technique 8      Analysis; CW Radiation; POE Direct Drive  
(CW) POE Direct Drive (P)

Note (1) Questionable - Additional tests or analysis required

## SECTION 2

### SITE MODELS AND SITE DESCRIPTIONS

Of the many potential site geometries which will be encountered in the DNA C<sup>3</sup> Facility Assessment Program, four generalized classes were chosen which bound, or typify, the majority of these sites. For each of these four classes, a generic site model was generated which incorporates the characteristic parameters of the class. When the four generic models typifying each class were completed, an actual site closely resembling the generic model was chosen for each class. This section presents descriptions of both the generic sites and the actual sites chosen. Table 2-1 summarizes the main characteristics of the four classes of sites.

#### 2.1 GENERIC SITE DESCRIPTIONS

##### 2.1.1 Site 1

Figure 2-1 portrays the generic model typical of Class #1. This model is centered about a buried central building functioning as a communication center. This building is both buried and shielded and has treated, hardened penetrations. All penetrations regardless of the nature or source, enter through an EMP vault which contains surge arrestors, filters, and signal conditioning equipment. The site model incorporates most conceivable communication cable penetrations. This includes satellite up and down links, microwave links, L carrier communication links, local communications, HF, MF, and LF radio communications, etc. The ancillary building cables and antennas cover a large area, up to one kilometer square. The interconnected buildings are also diverse in geometry and function. Some of these buildings are buried, some are shielded, some are both and some are neither. Because of the large area and the diverse nature of the total site, only the central building, the communication center, will be the subject of a hypothetical vulnerability assessment.

Table 2-1

Summary of the Four Classes of Sites

- I. Large, Complex Site
  - Many interconnected buildings -- some buried, some shielded, some both, some neither
  - Many buried, shielded cables
  - Main buildings designed for EMP protection - shielding, EMP vaults, shielded doors, penetrations, ESAS, etc.
  - Many antennas
    - HF, VLF, MW Towers, SATCOM
  - Size 1 km square
- II. Buried and Shielded
  - Simplest possible site
  - Tower present or absent
  - Few cables -- buried and shielded
  - EMP shielding
  - Few antennas
  - No special protection on cables
- III. Buried and Unshielded
  - Tower present or absent
  - Several buried, shielded cables
  - No EMP shielding
  - Several antennas
- IV. Single Tall Structure, Partially Buried
  - Cylindrical shape
  - Communications (MW) equipment on top
  - EMP shielding -- partial (walls only)
  - Internal cables, etc. -- mostly vertical
  - External POE -- typical power, utilities, no communication cables
  - Height 50 feet above ground

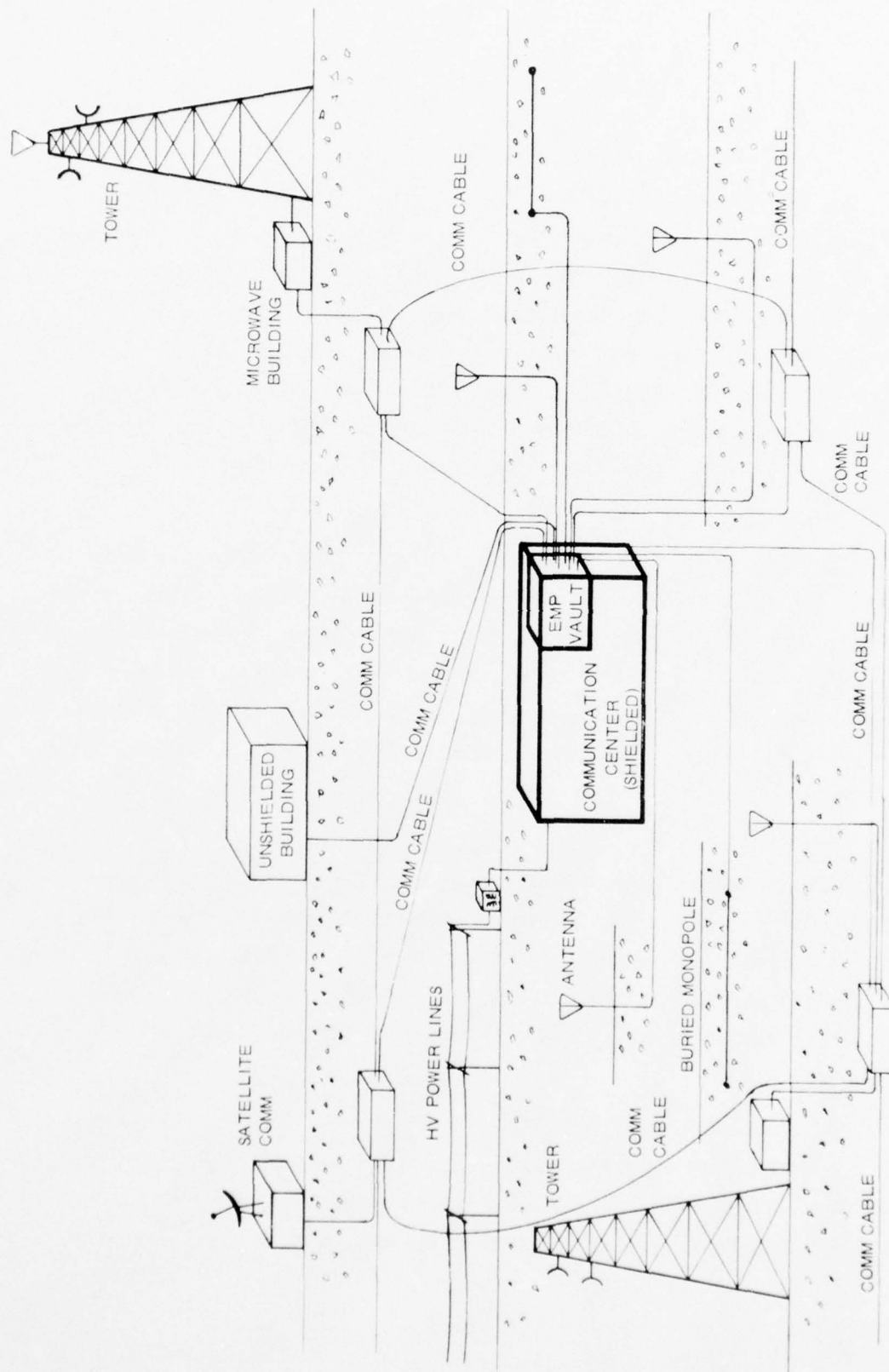


Figure 2-1. Site 1 Model

#### 2.1.2 Site 2

The generic model of Site #2, shown in Figure 2-2, typifies the simplest possible buried communication facility. This class of facility is buried and shielded, but does not incorporate specific EMP hardening treatment for its penetrations. This class of site is limited to a minimum number and type of penetrations. This includes power lines, a buried communication cable, and limited number and variety of antennas. This type of facility, which incorporates EMP field shielding around the building but does not incorporate EMP hardening of the penetrations is typical of facilities designed in the middle and late 60's. This model may include a possible microwave tower.

#### 2.1.3 Site 3

Figure 2-3 portrays generic Site #3. Site #3 is a buried and unshielded site. The major differences between Site Model 2 and Site Model 3 is the absence of shielding on the buried facility in Site #3. In addition, Site #3 is more complex in that it incorporates a larger variety of penetrations. Specifically, a larger number of antennas and communication cables are present. This type of structure, i.e., buried but unshielded, is typical of facility designed or constructed in the late 50's and early 60's.

#### 2.1.4 Site 4

Class #4 was chosen because it represents a number of facilities which are partially buried rather than completely buried and partially shielded. Site #4 generic model is shown in Figure 2-4. Class #4 is a "hybrid" model because it is only partially buried and only partially shielded. It is representative of a large number of sites which do not clearly fall into the preceding three classes.

### 2.2 ACTUAL SITE DESCRIPTIONS

A brief overview of the four actual sites selected for this study is given in Table 2-2. The table contains short lists of the sites' characteristics. The characteristics for each site typify one of the four classes of generic sites.

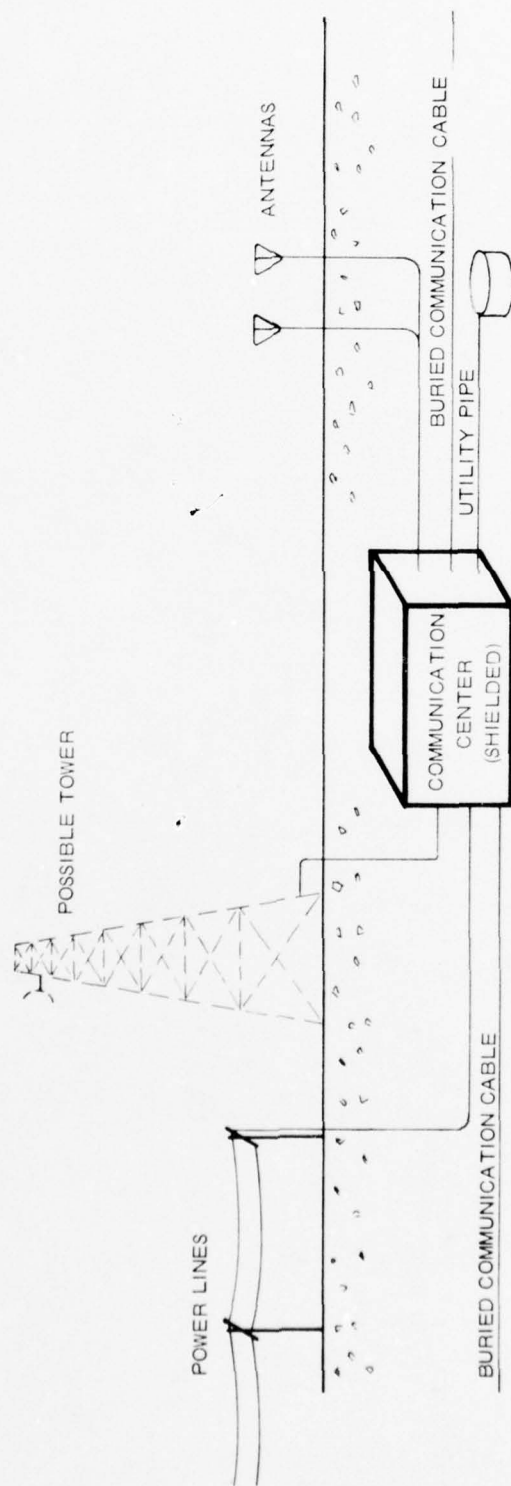


Figure 2-2. Site 2 Model

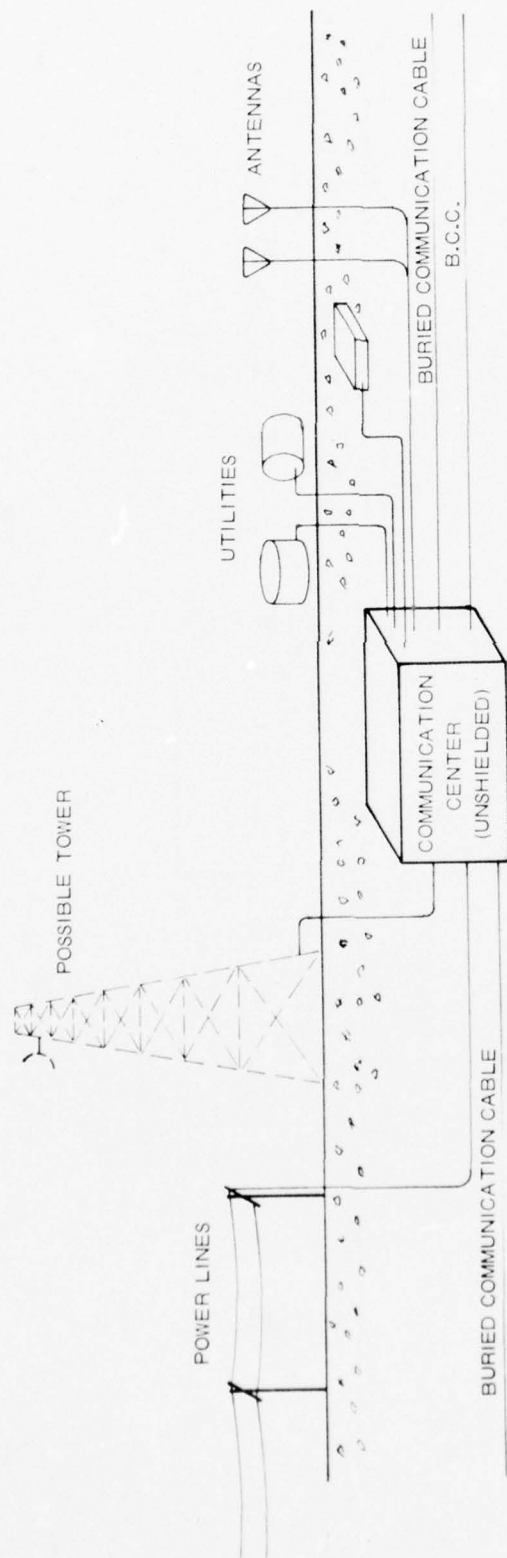


Figure 2-3. Site 3 Model

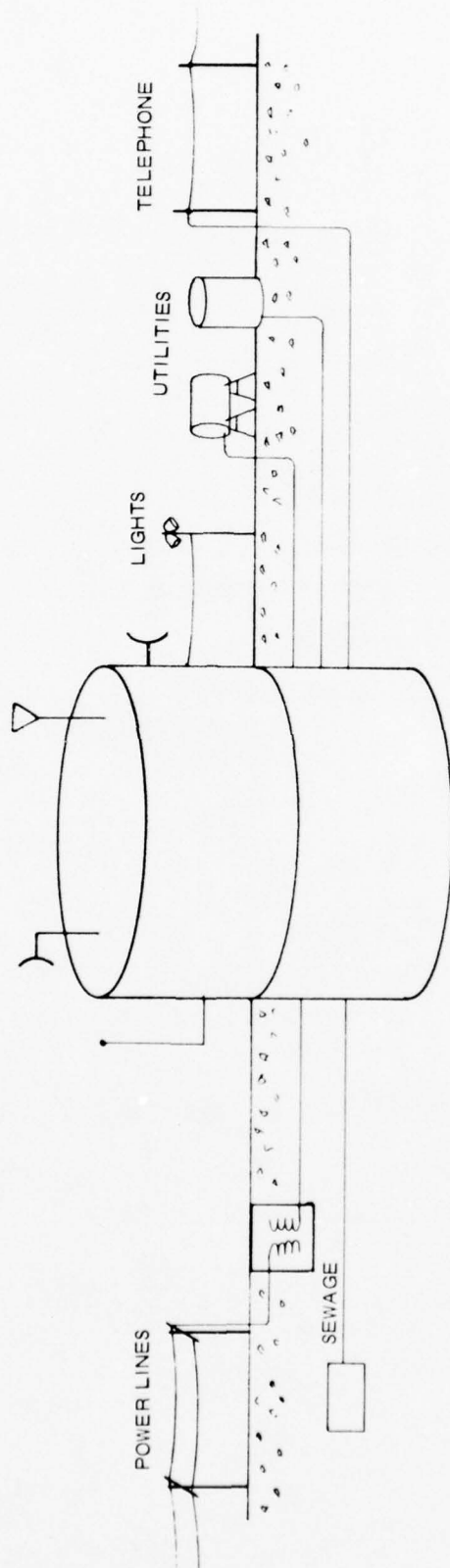


Figure 2-4. Site 4 Model

Table 2-2  
Overview of the Four Sites Chosen and Rationale

- I. Site 1
  - Most Diversity of POEs
    - Buried Cables/VLF Antennas
    - HF Antennas
    - Two Microwave Towers
    - Satellite Ground Terminal
  - Large Size: Greater than 1 km square
  - Designed for EMP Hardness
- II. Ellisville, Florida. Ground Entry Point
  - Simplest Site Possible
  - One Building
  - No Tower
  - Shielded
  - Few Antennas and Cables
- III. Lamar, Colorado. Ground Entry Point
  - More Typical, in the Middle of the Spectrum
  - Unshielded
  - Microwave Tower 75' from Building
- IV. Site 4 Microwave Station
  - Partially Buried Tall Structure
  - Partially Shielded
  - Blast Hardened
  - Few POEs

2. 2. 1

Site 1 Description

The major EMP characteristics of Site 1 are listed in Table 2-3.

Table 2-3

Site 1 Description

Plan View and Dimensions

- See Figure 2-5

Point of Entry List

- Direct penetration
  - All buildings and cables EMP shielded
    - 4mm thick welded steel
    - Cables into buildings via EMP vaults
  - Main building 104m x 90m x 15m high; buried 5m
  - Four buried switch facilities
- Two microwave towers (62m) and facilities - above ground
- Two VLF/LF antennas - buried horizontal monopole
- Four HF antennas - horizontal dipole/whip
- Satellite ground terminal - dish antenna and facility - above ground
- Two switched telephone lines - into switch point - buried
- One leased communication cable - into switch point
- Primary power - above ground into site
  - Shielded transformer at each building
  - Secondary lines in buried conduit
  - Into building via EMP vaults

Important Features and Peculiarities

- Large, complex site - many buildings, cables, POE's
- Designed to be very hard to EMP
- Impossible to simultaneously illuminate entire site

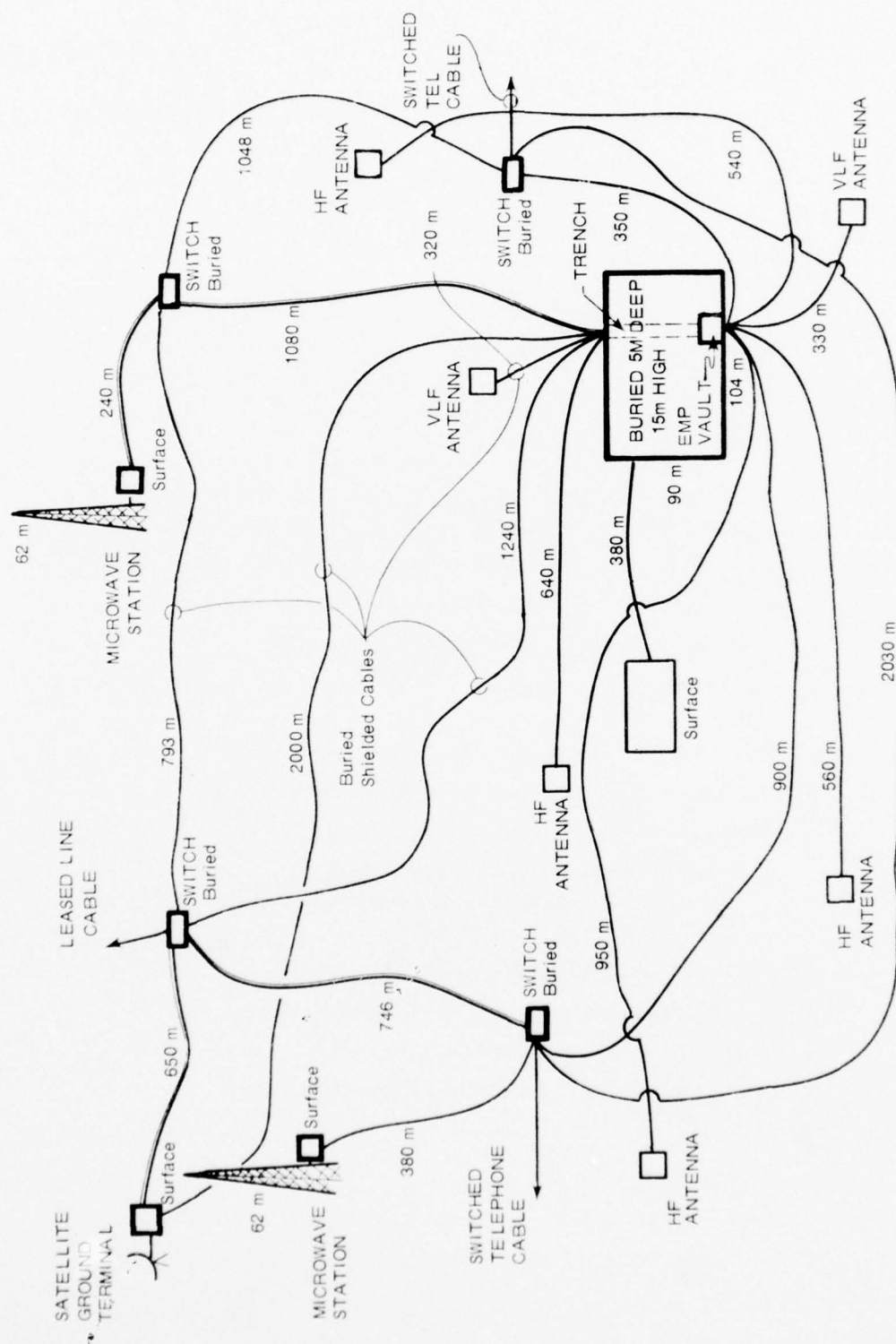


Figure 2-5. Site 1 Plan View

### 2.2.2 Site 2 Description

The major EMP characteristics of Site 2 are listed in Table 2-4.

Table 2-4  
Site 2 Description

#### Plan View and Dimensions

- See Figure 2-6

#### Penetrations

- See Table 2-5 of antennas

#### Important Features and Peculiarities

- EMP Shielded building
- No tower
- Few penetrations

#### Main Building

The building is a concrete rebar structure designed for survival to 50 psi. Equipment installed in the building is shock mounted to withstand an overpressure of 50 psi. The bottom slab is 38.2 feet below the roof slab. There is an average of 5 feet of soil above the top slab. In addition, there is an above-ground portion of the structure which contains an equipment shaft hoist and entrance doors. The reinforcing bar size and spacing vary. The average size is 7 gauge at an average spacing of 2 feet. The rebar is tied together everywhere with 10-gauge iron wire, (Reference 9).

The concrete thickness varies as follows:

Top slab = 2 feet

Bottom slab = 2 feet

Middle floor = 12 inches

Outside walls = 1 foot, 6 inches

There is a second building, structurally separated from the main building, which has a garage and storage area. There is no access to this building below ground. Electrical power and water are supplied via conduit and pipe running underground from the main building.

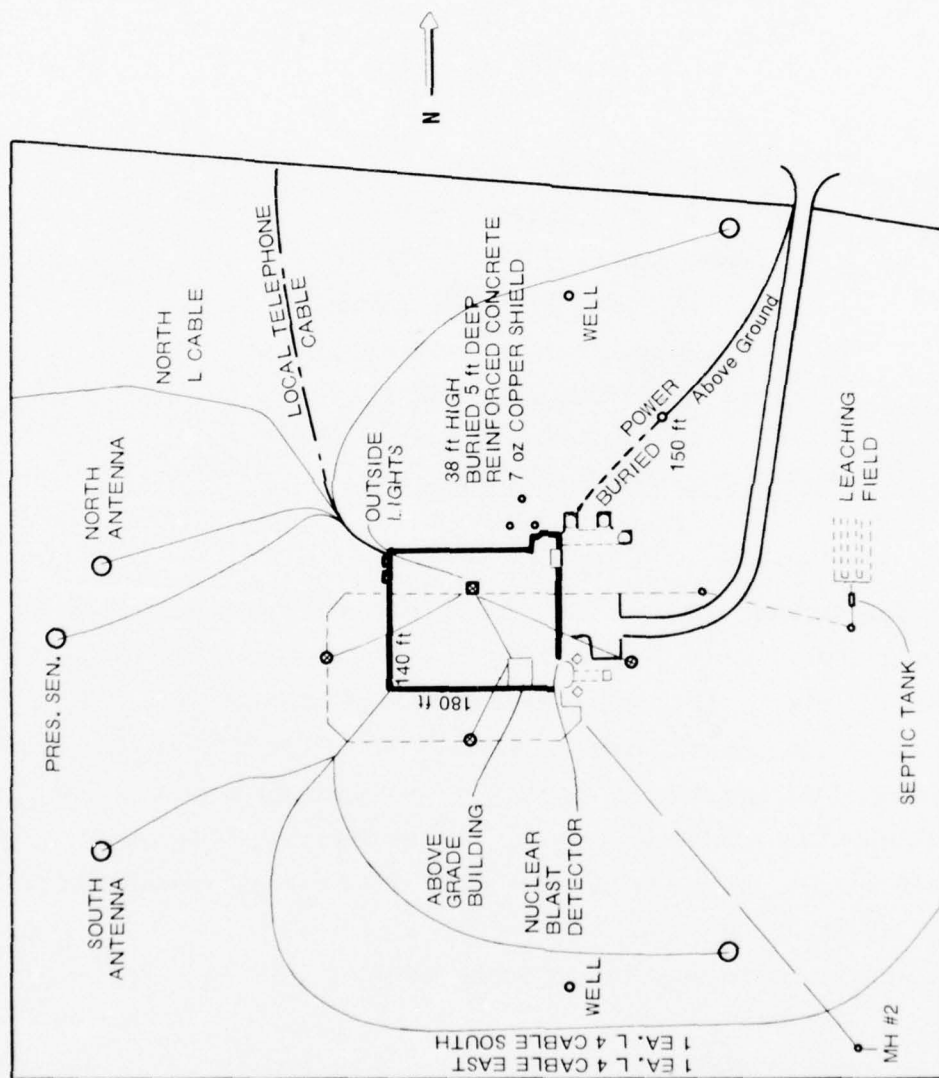


Figure 2-6. Site 2 Plan View and Dimensions

TABLE 2-5  
SITE 2 ANTENNA AND CABLE PENETRATION

SYSTEM	FREQUENCY	QUANTITY IDENTIFICATION	SIGNAL TRANSPORT	TRANSPORT OUT	LENGTH IN	PROTECTION	GROUNDING
NEACP	225-4000 MHZ	2 SETS CHU 3018H	HL-7-50 1 5/8 IN. HELIAX	310 FT. 350 FT.	204 FT. 166 FT.	LIGHTNING ARRESTOR AND EMP PROTECTION	A

<sup>A</sup> GROUND 6 FT. INSIDE BUILDING WITH A 17-FT. GROUND WIRE TO A GROUND BUS WHICH IS CONNECTED TO SWITCHGEAR GROUND AT LOWER LEVEL.

TYPE	LINE FREQUENCY	CIRCUITS/ CHANNEL	CHANNELS/ ROUTE	NEAREST REPEATER	COMMENTS
L-4 20 TUBES	512-17548 KHZ	3600	32400	2 MI.	A B C
L-4 12 TUBES	512-17548 KHZ	3600	18000	2 MI.	A B C
L-4 20 TUBES	512-17548 KHZ	3600	32400	2 MI.	A B C

<sup>A</sup> THE CABLE HAS 118C LIGHTNING PROTECTORS AT PIPE FITTED UNDER CROSSINGS (NEAREST) ONE TO THE SITE IS AT HIGHWAY CROSSING.

<sup>B</sup> CARBON BLOCKS ARE CONNECTED TO THE PAPER PAIRS APPROXIMATELY 6-1/2 FT. FROM THE SPLICE WHICH IS 5 FT. FROM THE PENETRATION POINT.

<sup>C</sup> CABLE LEAD SHEATH IS GROUNDED WITH 1 FT. LONG 4 GAUGE STRANDED WIRE TO PENETRATION PIPE AND THE PIPE IS GROUNDED WITH A 2/0 GAUGE STRANDED WIRE TO REINFORCING BARS IN THE CONCRETE.

The earth resistivity for this site is estimated to be 15 to 20 ohm-m since the bottom slab is close to the water table.

For protection from lightning and EMP, the building is wrapped with a 7 ounce copper sheet which is attached to the peripheral ground rods.

Ground rods surround the perimeter of the building and are spaced every 10 feet. The ground rods are 0.75 inches in diameter and 10 feet long of copper-clad steel.

#### Waveguides and Transmission Lines

There are no waveguides, horns, or tower at this site. This site does not have any soft CHU-1085 antennas.

#### Hard CHU Antenna

The four hardened antennas (CA-3018H) are located approximately 285 feet due west of the main building and are placed on two separate towers.

The cables from each of the hard CHU antennas penetrate the ground at the antenna base. The cables run 310 feet to 350 feet to the building.

#### Carrier Cables

The three L-4 cables are approximately 2 inches in diameter and each has an 1/8 inch lead shield covered by an 1/8 inch insulator.

#### Antennas

The only antennas that exist at this site are (1) FM antenna and (2) CHU-3018H hard antennas.

#### Local Telephone Lines

One 1.25 inch diameter local telephone line cable (buried) enters the building.

#### Primary Power

The main power lines approach the site from the northeast above ground. At a point 150 feet from the northeast corner of the building, the power lines enter the ground. The power cables are encased in one conduit (which is in concrete). Each conduit is 4 inches in diameter, separated from each other by 3 inches, and travels approximately 1 foot underground to the power transformer located at the northeast side of the building.

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2.2.3 Site 3 Description

Site 3 is characterized as a buried unshielded building, slightly more complex in nature than Site 2. Table 2-6 presents the major EMP related characteristics. A plan view is shown in Figure 2-7.

Table 2-6

Site 3 Description

Plan View and Dimensions

- See Figure 2-7

Penetrations

- See Table 2-6

Important Features and Peculiarities

- Typical ground entry point
- Buried, unshielded construction
- Microwave tower and L cables

Main Building

The building is a concrete rebar structure designed for survival to 50 psi (Reference 9). The bottom slab is 38 feet below the earth's surface. There are about two feet of soil above the top slab. In addition, there is an above-ground portion of the structure which contains a two-car garage, louvered intake air for air conditioning, and entrance doors. The rebar spacing varies from 8 to 12 inches. The rebar is tied together everywhere except at the I-beams, where it is welded.

The concrete thickness varies as follows:

Top slab = 2 feet

Bottom slab = 2 feet, 2 inches

Middle floor = 12 inches

Outside walls = 1 foot, 6 inches

A second building, structurally separated from the main building, houses a garage and storage area. There is no access to this building below ground. Electrical power and water are supplied to it via conduit and pipe running underground from the main building.



Table 2-7  
SITE 3 PENETRATIONS

DESCRIPTION	SIZE AND MATERIAL	LENGTH OUTSIDE/INSIDE	COMMENTS
POWER LINES			
		400 FT. TERMINAL POLE TO TRANSFORMER PAD/ 50 FT. TRANSFORMER PAD TO SWITCH GEAR.	LIGHTNING ARRESTOR ON TERMINAL POLE. PROTECTIVE DEVICE ON SECONDARY. CIRCUIT BREAKERS AND FUSES AT SWITCH GEAR.
ELECTRICAL CONDUIT TO GARAGE	1-IN. STEEL	100 FT./125 FT.	CIRCUIT BREAKER.
WATER LINES	<div> <div>2-IN. STEEL DISCHARGE LINE</div> <div>3/4-IN. STEEL VENT LINES</div> <div>2-IN. STEEL SUPPLY</div> <div>2-IN. STEEL RETURN</div> <div>2-IN. STEEL VENT</div> </div>	<div>500 FT. - 725 FT. / --</div> <div>50 FT. - 7 FT. /</div> <div>8 IN. - 20 FT.</div>	<div>SUPPLIES WELL WATER TO STORAGE TANK.</div> <div>VENT LINE PENETRATES SOUTHWEST CORNER OF BUILDING</div> <div>SUPPLY AND VENT LINES PENETRATE FAN ROOM WEST WALL.</div> <div>RETURN LINE EXISTS BUILDING THROUGH PUMP ROOM WALL.</div>
SEWAGE LINE	4-IN. CAST IRON	400 FT./20 FT.	DISCHARGED FROM EJECTOR IN PUMP ROOM VERTICALLY UP WEST WALL.
WASTE LINES	<div>6-IN. CAST IRON</div> <div>4-IN. CAST IRON</div>	<div>250 FT. / --</div> <div>80 FT./30 FT.</div>	<div>CONNECTS MANHOLE AT NORTHWEST COR- NER WITH DRY WELL.</div> <div>FOUNDATION DRAINS FEED BOTTOM OF MAN- HOLE.</div> <div>WATER COLLECTED FROM FLOOR DRAINS IS PUMPED FROM PUMP PIT THROUGH THIS WASTE LINE.</div> <div>MATES WITH 6-IN. LINE NEAR MANHOLE.</div>
FUEL LINES	1.5-IN. TO 2-IN. COPPER	140-FT. - 200 FT./30 FT.	FUEL LINES ENTER ENGINE ROOM SOUTH WALL.
BLAST DETECTOR	1-IN. CONDUIT	190 FT./1 FT.	CABLE ROUTED WITHIN EXISTING 4-IN. X 150- FT. CONDUIT ON WEST SIDE. CABLE ENTERS JUNCTION BOX IMMEDIATELY AFTER PENE- TRATION AND IS GROUNDED.

Table 2-7 (continued)

## SITE 3 ANTENNA AND CABLE PENETRATION

SYSTEM	FREQUENCY	QUANTITY IDENTIFICATION	SIGNAL TRANSPORT	TRANSPORT OUT	LENGTH IN	PROTECTION <sup>A</sup>	GROUNDING
TD-2	3700 TO 4200 MHZ	4 KS-15676	WAVEGUIDE	465	60	NONE	SUPPORT STRUCTURE RADIO RACK
TL	10.7 TO 11.7 GHZ	1 KS-19570	WAVEGUIDE	500	30	NONE	SUPPORT STRUCTURE RADIO RACK
TM	5925 TO 6425 MHZ	DISH	WAVEGUIDE	500	30	NONE	SUPPORT STRUCTURE RADIO RACK
MOTOROLA	UNKNOWN	1/ANDREW 150-1	COAX CABLE	465	60	NONE	AT RADIO RACK
WWV	2.5 TO 25 MHZ	1 WIRE AND HORN	COAX CABLE	150	50	YES (?)	AT RELAY RACK
PACCS (SOFT)	225 TO 4000 MHZ	2 CHU-CA-1085	HF7-50A 1.675 IN. HELIAX CABLES	725	75	118D OUTSIDE BUILDING	AT SUPPORT STRUCTURE, AT WAVEGUIDE ENTRANCE, AT PATCH PANEL
PACCS (HARD)	225 TO 4000 MHZ	2 CHU-CA-3018H	HF7-50A 1.675 IN. CABLES	710(U)	75	118D OUTSIDE BUILDING	OUTSIDE UNKNOWN AT PATCH PANEL
TYPE	LINE FREQUENCY (KHZ)	CIRCUITS/CHANNEL	CHANNELS/ROUTE	NEAREST REPEATER (MI)	COMMENTS		
L-1	64-3696	600	1800	6	118A PROTECTOR OUTSIDE BUILDING (150 FT.) NO. 123A1A INSIDE		
L-3	308-8320	1860	9300	4	118D PROTECTOR OUTSIDE BUILDING (150 FT.) NO. 123A1A		
L-3	308-8320	1860	9300	4	118A REMOVED (1968) NO. 123A1A INSIDE		

<sup>A</sup> LIGHTNING ROD AT TOP OF TOWER

The earth resistivity for this site was 49.7 ohm-m.

#### Waveguides and Transmission Lines

The waveguides extend from the horns at the top of the microwave tower (350 feet above ground) to a point about 5 feet above ground. The waveguide is grounded to its supporting structure at several points by two-gauge stranded wire about 2 feet long. The supporting structure is tied to the ground loop just above the waveguide shaft entrance by #2/0 AWG stranded wire which extends into the ground loop from one leg of the structure. The visible portion of this wire is 3 feet long.

No protection devices are present on the waveguides; however, there is a lightning arrestor at the top of the tower.

#### Soft CHU-CA-1085 Antennas

Two soft antennas, both type CHU-CA-1085, are 300 feet due north of the radio relay tower and are 25 feet apart in the northerly direction. The antenna is 26.75 inches high and 14 inches in diameter. This antenna operates over the 225- to 400-MHz frequency band with gains over 6.0 dB and VSWRs less than 2.0:1.0. The cables enter the ground at the support slab and remain underground (~2 feet) to the radio tower, where they enter the waveguide support structure at the base of the tower. These cables follow the waveguides along the support structure, down the waveguide duct, and eventually enter the building at the east wall 26 feet below ground.

#### Hardened CHU-301H Antennas

The hardened (50 psi) antennas are located approximately 400 feet due north of the relay tower. These antennas are collocated on a single tower and are CHU type CA-3018H. The hardened antenna produces a normal dipole pattern and covers the 225- to 400-MHz frequency band with a VSWR less than 2:1 on 50 ohms. The package is 5 feet tall and 29.5 inches in diameter. The antenna feed design provides a high-capacity dc path to ground for protection from EMP and lightning.

### Carrier Cables

The L-1 coax cable is about 2 inches in diameter and has 0.125 inches lead shield covered by a 0.125 inch insulator. This cable enters the building more than 30 feet below the ground surface. It is buried at a depth of 4 feet after leaving the building. The two L-3 coax cables are about 3 inches in diameter and have an 1/8 inch lead shield covered by 1/8 inch insulator. Entry and burial depth are similar to the L-1 cable.

### Tower and Tower Equipment

The microwave relay tower is located about 75 feet from the north-east corner of the main structure. The height of the tower, which contains a lightning arrestor at the top is 350 feet.

The following equipment is located on the tower:

1. Two P20120 10-foot parabolic dish antennas. One is located from ground level and uses two transmission lines. The second is located 337 feet from ground level, and uses two waveguides.
2. Four KS-15676HR microwave horns, located at 350 feet. Each employs two waveguides.
3. One Andres 150-1 antenna, located at the 350 foot level and used for local two-way radio communication.

### Local Telephone Lines

Two local telephone lines penetrate the building. Number 1 provides service to the adjacent satellite communications building (approximately 400 feet away). This cable, about 1.5 inches in diameter, remains underground (about 4 feet) between the two buildings and enters the building about 2 feet below the top slab of the radio power room. This line carries voice and teletype.

Number 2 provides service to a city 11 miles away. This cable, about 1 inch in diameter, is underground from the city to the site.

### Primary Power

The main power lines approach the site from the east above ground. At a point 125 feet from the southwest corner of the building the power lines enter the ground. The power cables are encased in two conduits, which are

encased in concrete. Each conduit is 4 inches in diameter, separated from each other by 2 inches, and travels approximately 1 foot underground to the power transformer located at the eastern side of the building. A set of lightning arrestors is located on the last pole before the power cable enters the ground.

#### WWV Antenna

A WWV antenna which is a small (1 foot length) horn, is mounted on an 8 foot pole on the eastern side of the building. A 0.5 inch diameter coax runs from the horn to the waveguide and enters through the wall in the radio room.

#### 2.2.4 Site 4 Description

The plan view for site number 4 is shown in Figure 2-8. An elevation view of the central microwave tower is shown in Figure 2-9. This is a 50 psi blast hardened building, it does not have an integral EMP shield or EMP treated penetrations. There is some steel lining on the vertical rolls which will provide some EM shielding. However, since this lining does not cover the entire building, there will likely also be some local field enhancement and re-radiated fields inside. Until some testing or more detailed site survey and analysis show otherwise, Site 4 should be considered as an unshielded building. A typical power pole treatment is shown in Figure 2-10.

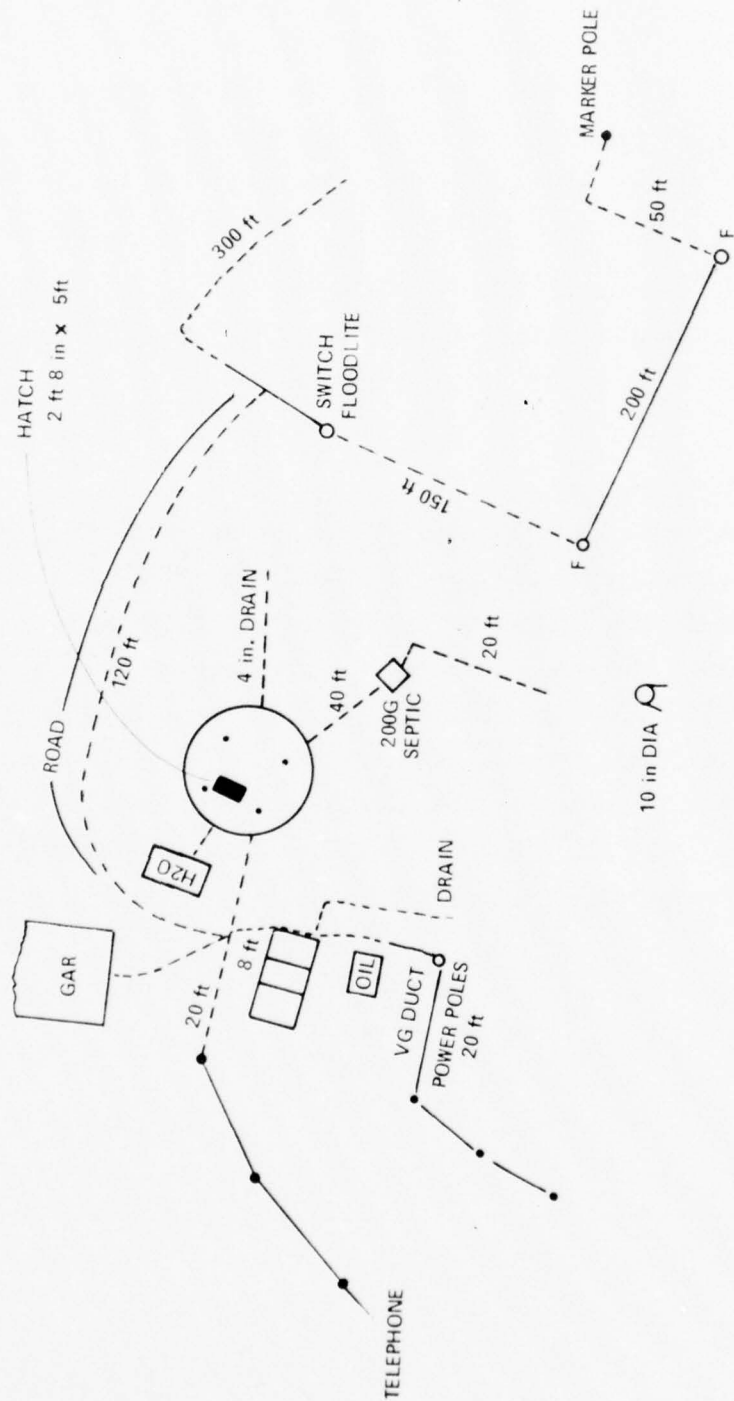
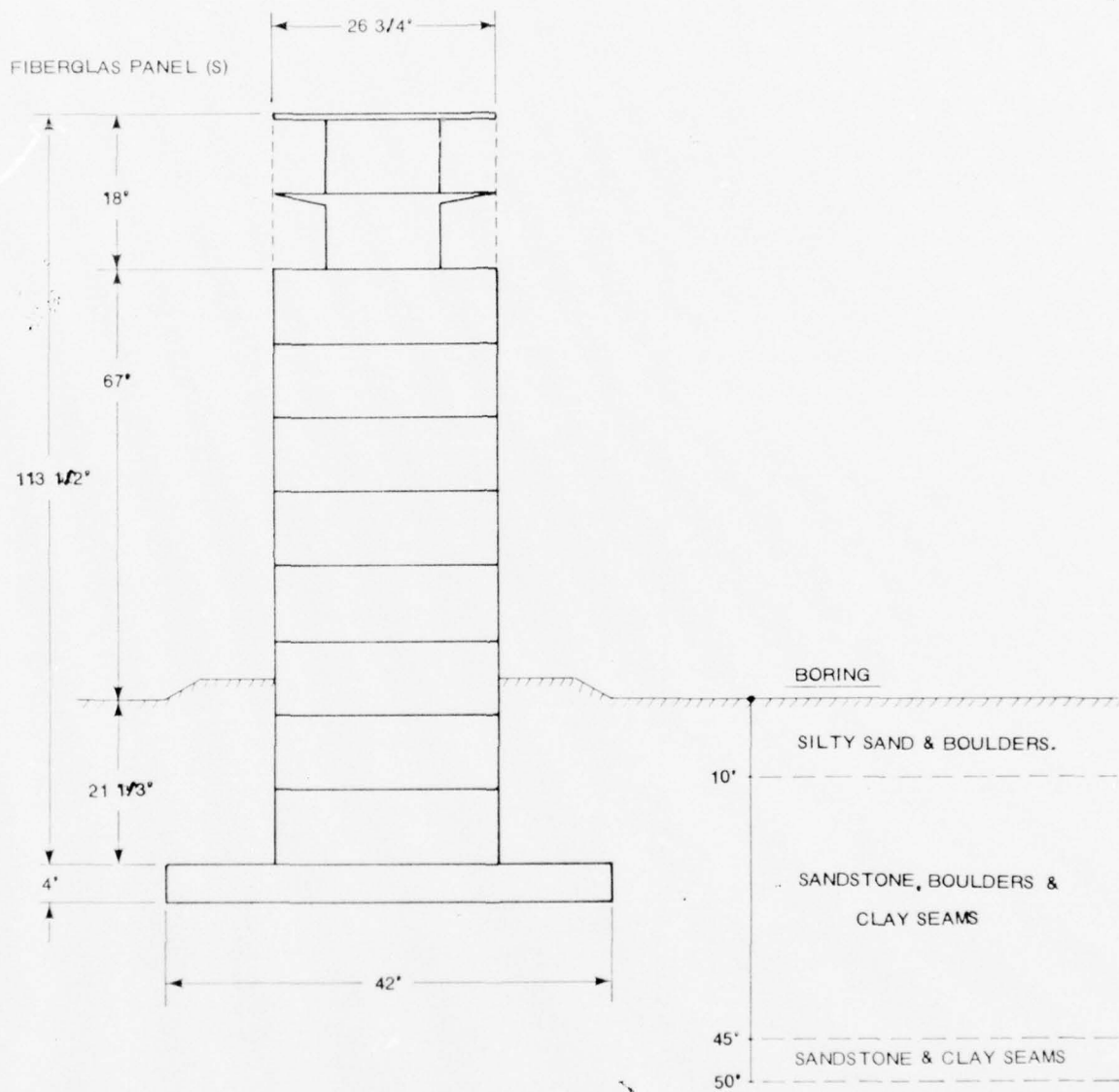


Figure 2-8. Site 4 Plan View



WALLS: 1 3/4" THICK. SOME BLDGS. WITH STL. PLATE LINERS INSIDE & OUTSIDE.

FLOORS: TYP. 1" THICK.

ELEVATOR UP ONE SIDE FROM BASEMENT.

NO WATER TABLE REACHED.  
DENSITIES: 156-166 PCF.  
% ABSORPTION: 3.5-4.2

Figure 2-9. Typical Microwave Tower-Elevation View

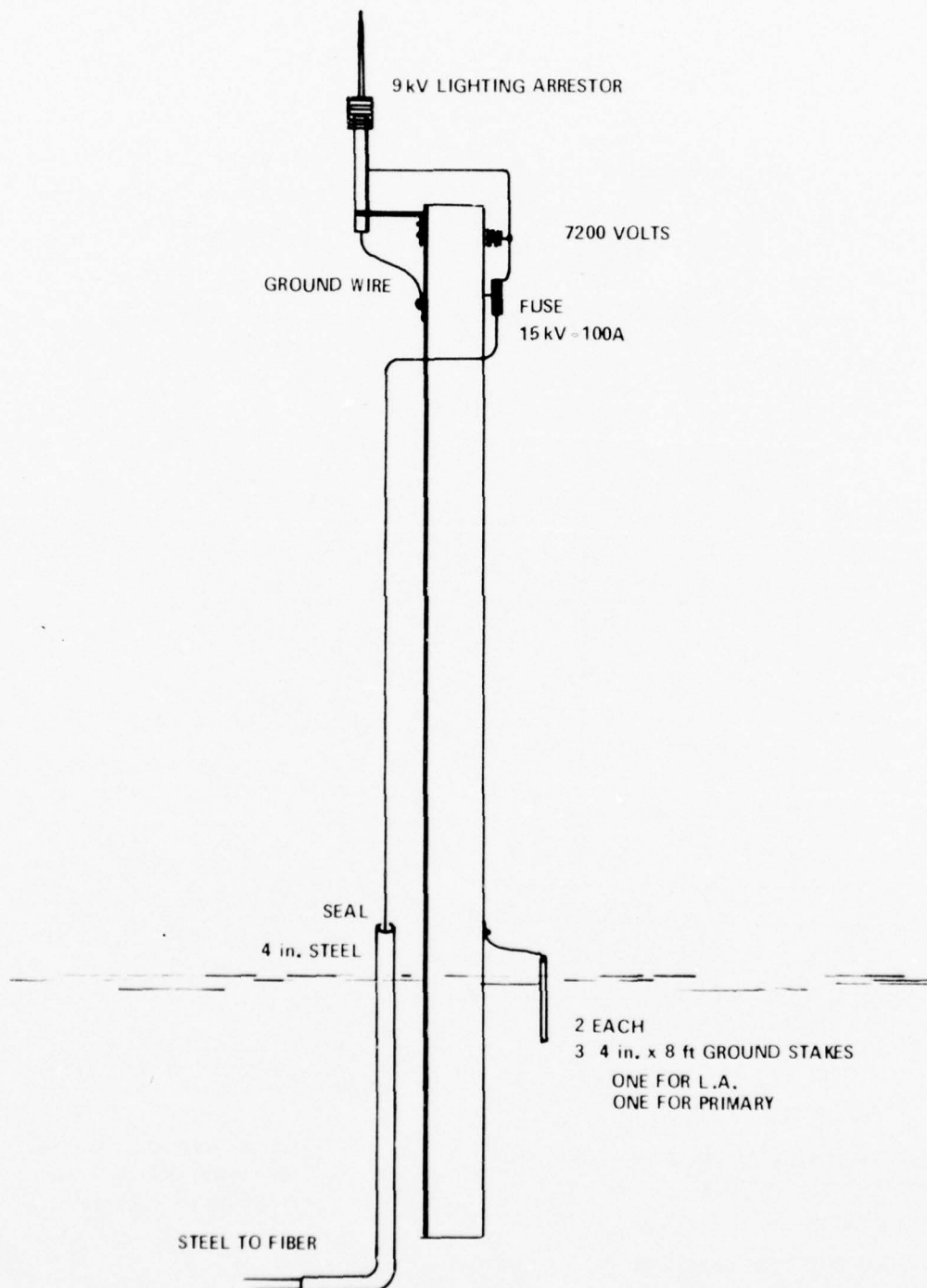


Figure 2-10. Site 4 Power Line Pole-Mounted Transformer and Ground

## SECTION 3

### ASSESSMENT METHODS AND APPLICATIONS

There are numerous experimental techniques which can be used in an EMP assessment program. Because no single experiment can provide all the data needed to complete an assessment of a complex site, the common approach in the EMP community today is to use tests as a means of reinforcing and/or verifying analysis.

Each of the various test methods is designed to provide insight into some portion of the assessment problem. In order to more intelligently discuss the usefulness of each test method we will first discuss the major elements in an EMP assessment program.

#### 3.1 EMP ASSESSMENT APPROACH

The essential elements of an EMP vulnerability assessment of a C<sup>3</sup> site are:

1. Determination of site electromagnetic environment.
2. Determination of voltages and currents induced by external points of entry such as cables, towers, pipes, etc.
3. Determination of the shielding effectiveness of the building structure.
4. Propagation of POE coupled signals in the interior of the structure.
5. Coupling of fields to internal conductors.
6. Determination of the damage and upset thresholds for the critical interfaces.
7. Determination of the functional response (in terms of site mission impairment) of the facility when the thresholds are exceeded.

In the course of an EMP vulnerability assessment, all of these requirements can be partially satisfied by analysis. However, to increase the confidence in the assessment, (i.e., to decrease the error bound), verification testing is frequently done.

In the evaluation of suitable assessment techniques for the four selected sites, each technique will be examined to determine how well it fulfills the preceding requirements as they are applied to each particular site. For each site, some site unique features will simplify, eliminate, or add confidence to some of the elements of the analytical assessment. For instance the use of a well shielded enclosure whose electromagnetic attenuation is known, eliminates the necessity for measuring or calculating the shielding effectiveness of the building, or the coupling of the fields of internal conductors.

### 3.2 ASSESSMENT METHODS AND APPLICATIONS

#### 3.2.1 Analysis

3.2.1.1 Definition. Analysis comprises all those analytical or computational methods used to predict the response of a  $C^3$  facility to a threat level EMP. Since the primary analytical tool of the DNA  $C^3$  EMP Assessment Program is the PRESTO code, it is assumed that predictions will be generated using this code, or some equivalent code whose accuracy is known for these applications.

In most current large scale EMP assessment programs, analysis consists of:

1. Developing computerized models of the electrical geometry of the site, and using these models to predict voltages and currents at points of interest throughout the site, e.g., POEs, critical interfaces, etc.
2. Determining by hand analysis, or from a suitable data base, the damage and upset threshold at the critical interfaces.
3. Comparing 1 and 2 to arrive at a probability of failure, the failure mode, and its effect on the site mission.

Other analytical approaches and methods are commonly employed on simpler, more tractable problems, for example a calculation of the EMP response of a deliberate antenna whose frequency response is well known.

3. 2. 1. 2 Application. Analysis, in its more general meaning, can be used on any or all of the elements of an assessment program. It is quite common for a site to be completed utilizing only analytical or computational predicted methods. The usefulness of the test techniques is to increase the accuracy and the confidence of an analytical assessment by verifying the accuracy of the predicted model.

3. 2. 1. 3 Accuracy. One of the most important of the evaluation criteria used in this study is accuracy. As applied to a test or measurement method accuracy refers to a one sigma error bound. That is 68% of the measurements will have errors smaller than the stated error bound. When the term is applied to a prediction or an assessment (whether of a circuit or a site) the term means that 68% of the population of identical circuits (or sites) will have responses within the specified error bounds. The current capability for accurate analytic predictions of electromagnetic response is shown in Figure 3-1a, taken from Reference 1. The charted errors are for a one sigma confidence interval. The cumulative error in proceeding to greater levels of complexity adds linearly in the chart, i. e. they are not statistically independent. Thus a test or measurement which refines predictions from level to level reduces the overall error by the difference between charted error and measurement error. For instance, the total cumulative error in an analytic prediction at level 6 is 22 dB. A one- $\sigma$  measurement of the total coupling to level 5 with an error of  $\pm 2$  dB removes 17 (19 minus 2) dB of uncertainty. Predictions at level six can now be made with only 5 (22 minus 17) dB error. The levels of complexity used in this chart are defined in Figure 3-1b.

This chart does not take into account uncertainties in the determination of damage and upset thresholds or in predicting the functional response. Prediction of failure thresholds by hand analysis, by recourse to a data base, or by comparison to known devices, contains uncertainties of approximately  $\pm 5$  dB. Black box or devices testing refines the uncertainties to the spread within a device type caused manufacturing tolerances and item to item variations. This uncertainty is of the order of 3.4 dB. When these factors are added to the errors

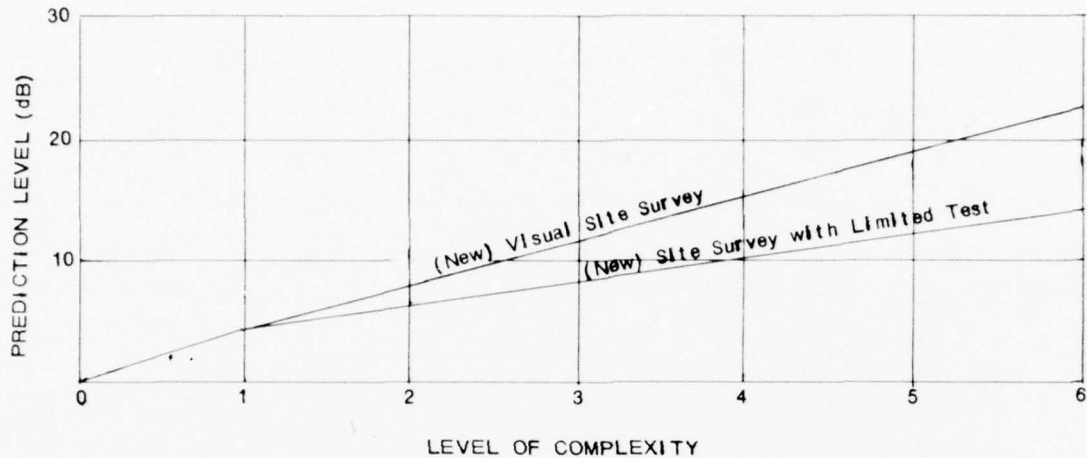


Figure 3-1a. Communications Facility Electromagnetic Response Capability

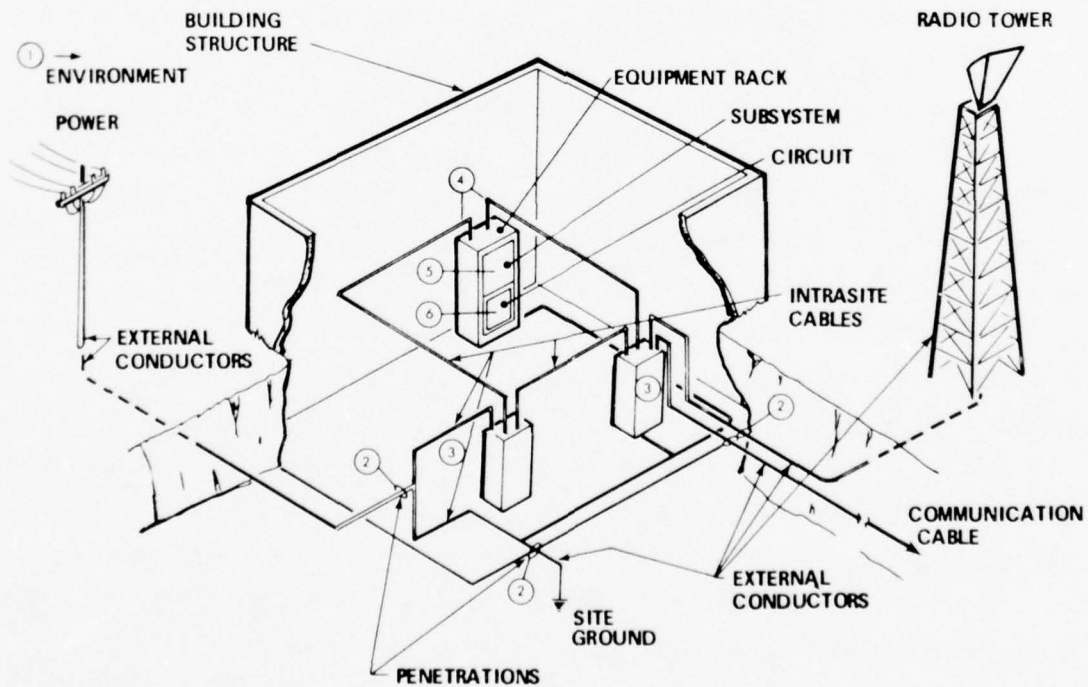


Figure 3-1b. Typical Communication Facility and Electromagnetic Prediction Levels of Complexity

shown in Figure 3-1, an analytic assessment of a site based on visual inspection only is seen to be accurate to within approximately  $\pm 25$  dB.

### 3.2.2 Point of Entry Direct Drive (Pulse)

3.2.2.1 Description. A point of entry is either an aperture in the site shielding or an extended antenna like object which can pick up relatively large EMP induced voltages and currents and couple them into the site. For this study we will use the latter definition. Sample POEs are power lines, telephone lines, sewer or water pipes, antennas, towers, etc. The electromagnetic response of a site is frequently dominated by its POE. This is particularly true in the case of a well shielded building. Because of the size and extension of the POEs, radiated or bounded wave illumination frequently fails to properly excite them. POE direct drive (pulse) is a direct excitation of POE by a high voltage stored energy pulser.

3.2.2.2 Application. Use of this technique allows one to measure directly in the time domain the transfer function from the POE to the critical interfaces. Use of high voltages and currents also drives the POE into its nonlinear range if one exists. It is often feasible to tailor the output waveshape by varying the output impedance or by using a waveshaping network. Thus, a waveshape similar to that predicted for the POE at threat can be injected. In this case, the tests (1) verify the predicted model, (2) verify nonlinear behavior, if any, and (3) yield threat related transfer functions which obviates the need for extrapolation. Nonthreat waveshapes are also useful because they perform (1) and (2) above.

Another type of POE direct drive (pulse) involves the use of a low level Broad Band Pulse (BBP). It is used in conjunction with a network or spectrum analyzer to measure the transfer function in the frequency domain. In this report POE direct drive (pulse) means high level excitation; BBP technique will be discussed along with its close relative CW direct drive.

3.2.2.3 Accuracy. In Reference 10, Chapter 8, it is stated that the dominant source of error is the deviation from the nominal transfer impedance of Stoddart or Singer probes. However, the transfer function for each individual probe is provided by the manufacturer as a function of frequency. This transfer function provided by the manufacturer is accurate to within  $\pm 1$  dB. This accuracy is quoted by the manufacturer. Because the transfer impedance is frequency dependent, it cannot be used to interpret pulse data in the time domain. However, with the use of proper algorithms, and a large scientific computer such as a CDC 6600 or equivalent, time domain data can be quickly transformed to the frequency domain, corrected for frequency dependence, and then transformed back to a time domain. The cumulative error in this process of digitizing, transforming, correcting, and inverting are approximately .6 dB under ideal conditions. A conservative estimate of a standard error in this process would be  $\pm 1$  dB. Because they are statistically independent, we add the errors in quadrature to yield an accuracy of  $\pm 17$  percent for the current measurement. Since the injected current and the test point current are both measured by similar probes, the error in the transfer function is approximately  $\pm 25$  percent, or 2 dB. The transfer function is defined:

$$X_{tr} = I_{\text{test point}} / I_{\text{injected}}$$

The voltage measurements uncertainties and calibrations of  $\pm 2$  dB were recorded in Reference 1. It is felt that improving the calibration procedures, even under field conditions, could bring this error down to 1.6 dB or  $\pm 20$  percent. Thus, the error in the transfer function

$$X_{tr} = V_{\text{test point}} / I_{\text{injected}}$$

is 26 percent or  $\pm 2$  dB. Thus, the average standard deviation for voltage and current transfer functions in a POE direct drive pulse test is  $\pm 2$  dB, and  $\pm 1.6$  dB for the individual measurements.

### 3.2.3 POE Direct Drive (CW)

3.2.3.1 Description. Sometimes it is impractical to use high level pulseders because of site assessability, site interference, time available, or other factors. A technique which uses off-the-shelf, relatively portable and inexpensive electronics is the CW direct drive technique. Tests can be run using either selected frequencies or a swept CW generator. This type of test utilizes such small signal levels that testing can be performed on an operating site with little or no interference to site operations. In a typical CW POE direct drive test, a swept frequency generator across the bandwidth of interest is used to inject signals at the point of entry, and a spectrum or network analyzer is used to record the data at the measurement points of interest, see Figure 3-2.

3.2.3.2 Application. The CW direct drive method is used to:

1. Measure parameters to be used in the modeling effort.
2. Identify points which are tightly coupled to POE's to direct the modeling effort.
3. Eliminate points which are not coupled to POE's from the modeling effort.
4. Verify predicted transfer functions after the fact.
5. Measure transfer functions directly.

Since low level signals are used, this method will not drive POE's or coupling paths into nonlinear regions. Therefore, this technique should be used with caution when nonlinearities such as electrical surge arrestors are known or suspected.

As mentioned in 3.2.2, an adjunct of low level CW direct drive is the low level broad band pulse test. It has all of the same advantages and applications of low level CW, but with a more restricted dynamic range.

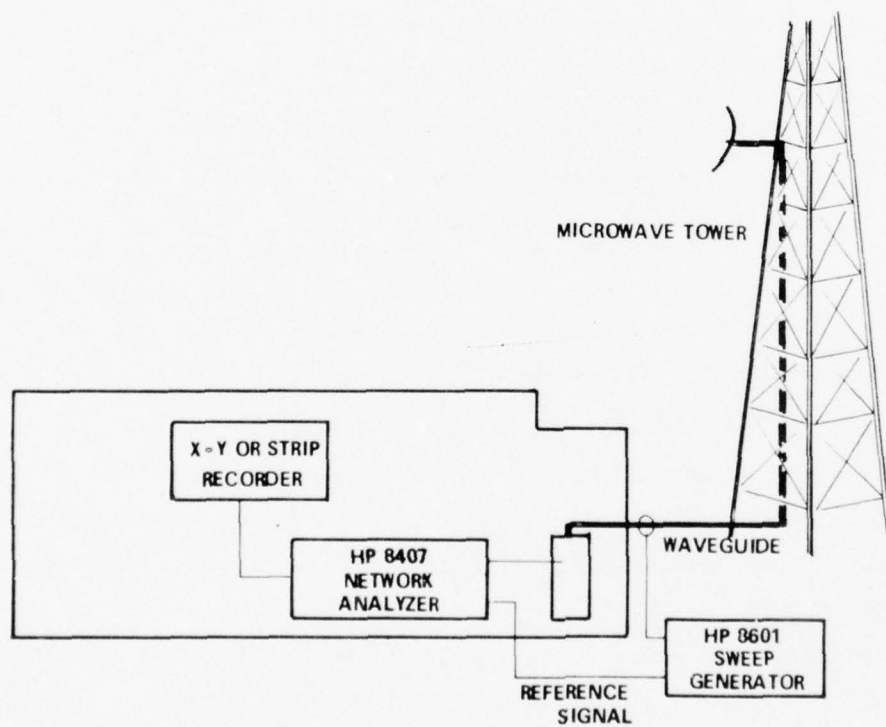


Figure 3-2. Typical POE Direct Drive (CW) Test Setup

3.2.3.3 Data Accuracy. The accuracy of the current probe in the frequency domain is  $\pm 1$  dB or 12 percent. The accuracy of the measurement can be limited by the width of the scope trace on the network or spectrum analyzer. Whichever is used, accuracies of 1 dB or 12 percent can be consistently achieved in the field if proper care and practice are used. Thus, for CW testing, transfer functions can be measured directly with an accuracy of  $\pm 17$  percent or approximately 1.5 dB.

#### 3.2.4 Pulse Radiating Simulation

3.2.4.1 Definition. An EMP simulator is a device which is capable of illuminating a test object with a radiated or bounded wave pulse of electromagnetic energy similar in waveshape to a high altitude EMP. There exists a number of such simulators in the U.S. today. A brief summary of their chief characteristics is shown in Figure 3-3. In this study we shall consider only portable simulators. The simulators to be evaluated are TEMPS, RES, and a hybrid simulator consisting of an existing pulser plus an underground array. Possible buried arrays are SIEGE type buried transmission lines, or buried Helmholtz coils.

3.2.4.2 Applications. The great advantage of full scale simulation is that it illuminates the entire test object with a threat like pulse. Thus, the interaction of the field with the building, local external POE's like area lighting, water pipes, and grounds, and interior conductors can be evaluated in a most realistic fashion. Because the total site is illuminated, a complete integrated predictive model can be verified. The one shortcoming of full scale simulation is that no simulator can cover a large enough area with a plain uniform wave front to adequately drive the long POE's such as power and phone lines. That is why in the past PREMPT TEMPS tests, cable driving was also performed on selected POE's.

SIMULATOR	PARAMETER	PULSE VOLTAGE	FIELD POLARIZATION	PEAK FIELD STRENGTH	FIELD UNIFORMITY				RISE TIME 10%-90%	FIXED TRANS- PORTABLE	DATA ACQUISITION CAPABILITY	O & M COSTS	O & M CAPABILITY
					100%	900%	9000%	90000%					
DIPOLE ARRAYS													
ALESS	2.2 MV	V	100 KV/IN	EXCELLENT	EXCELLENT	UNUSABLE	UNUSABLE	5-10s	F	EXCELLENT	15K PER MONTH	YES	
ARES	3.7 MV	V	90 KV/IN	BETTER THAN ± 20%	BETTER THAN ± 20%	± 20%	POOR	8s	F	EXCELLENT	2-2.5K PER DAY	NO	
THRETTLE	10-100V V 4MV	AND V	0-100 KV/IN V 50 KV/IN	BETTER THAN ± 20%	BETTER THAN ± 20%	± 20%	± 20%	20ms	F	EXCELLENT	125K PER MONTH	YES	
TEFS	100 KV	H OR V	85 KV/IN	EXCELLENT	EXCELLENT	GOOD	UNUSABLE	15-20ms	F	MODERATE	40K PER MONTH	YES	
HEMP	100 KV	V	80 KV/IN	EXCELLENT	GOOD	GOOD	UNUSABLE	10ms	F	EXCELLENT	10K PER WEEK	NO	
VERTICALLY POLARIZED RADIATORS													
VPC	1.8 MV	V	8 KV/IN AT 500'	12	10	11	± 10%	5-10s	F	EXCELLENT	10K PER MONTH	NO	
ORL	1.8 MV	V	80 KV/IN AT 1M	EXCELLENT (12)	EXCELLENT (17)	GOOD (4)	GOOD (4)	1-1s	F	POOR		NO	
LASL	100 KV	V	100 V/IN AT 1 MILE	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	1-10s	F	MODERATE		NO	
EMPRIS	2.5 MV	V	28 KV/IN AT 50 M	EXCELLENT	GOOD	GOOD	GOOD	4-10ms	F	MODERATE	4K PER WEEK	NO	
RES	1.8 MV	H OR V	800 V/IN AT 500'	EXCELLENT	EXCELLENT	± 10% (12)	± 10% (12)	4-6-10s	F	NO	10K PER WEEK	NO	
HORIZONTALLY POLARIZED RADIATORS-OR HYBRIDS													
LASL	120 KV	H	45 V/IN AT 1 MILE	EXCELLENT	EXCELLENT	EXCELLENT	EXCELLENT	1-10s	F	MODERATE		NO	
HPC	1 M OR 1.8 MV	H	25 KV/IN AT 1 M	EXCELLENT (12)	GOOD	POOR	POOR	4-10s	F	EXCELLENT	10K PER MONTH	NO	
SUPPLEMENTAL RES	1.8 MV	H	7 KV/IN AT 14 M	10	10	10	10	5-10s	F	EXCELLENT	4K PER WEEK	NO	
EMPRIS	2.5 MV	H	15 KV/IN AT 50 M	EXCELLENT	GOOD	GOOD	GOOD	4-10s	F	MODERATE	4 K PER WEEK	NO	
TEMPS	7 MV	H	32 KV/IN AT 50 M	BETTER THAN ± 10%	BETTER THAN ± 10%	± 10%	± 10%	5-10s	F	EXCELLENT	1-1.5M PER YEAR	NO	
RESOP	7 MV	H	52 KV/IN AT 500'	BETTER THAN ± 10%	BETTER THAN ± 10%	± 10%	± 10%	8-10s	F	EXCELLENT	10	NO	
MARTIN MARQUETTA LONGHIRE	250 KV	H	100 V/IN AT 1 M	EXCELLENT (12)	EXCELLENT	POOR	POOR (12)	3-100ms (VARIABLE)	F	EXCELLENT		NO	
SANDIA LONGHIRE	30 KV	H	400 V/IN AT 1 M	EXCELLENT (12)	EXCELLENT			1-10s	F	EXCELLENT		NO	
RES	1.8 MV	H OR V	800 V/IN AT 500'	EXCELLENT	EXCELLENT	± 10% (12)	± 10% (12)	4-6-10s	F	NO	10K PER WEEK	NO	

- For the 3m or 10m test object, all polarizations can be achieved by proper orientation of test object.
- Two separate simulators (H and V) form the THRETTLE facility.
- 1/r varying fields - good field uniformity attained by placing large test object near perimeter of 363m ground plane - but reduced field strength results.
- Transportable at high expense.
- Delta function pulse - 1 ns decay time also.
- For a double shift 5-day week and a crew of 10 (total).
- Very uniform in horizontal plane but large variations in field strength with height.
- Available to secondary user on non-interference basis only - possibly at no cost.
- Varies by a factor of ~3 over the 40 m wingspan of C-130 sized airplane.
- May be varied by changing pulse - test object distance - this will also affect field strengths.
- Horizontal, vertical and intermediate polarizations are possible.
- Risetime can be improved for small TEFS arrays.
- Includes 660K for large parking pad and tow-way.
- 1/r varying.
- For maximum field strength (~60m from source).
- Field uniformity for all horizontally-polarized radiators is reduced by ground reflections.
- Risetime increases with distance from the simulator due to ground losses.

Figure 3-3. Summary of Simulator Systems

The advantage of threat level simulation is that the functional response of the site to a threat EMP can be measured directly. Nonlinearities on the small POEs or in the internal coupling paths or their terminations can be measured directly. Also, because the high level pulse will give more signal, the dynamic range of the test is extended. Low level testing is also useful but does not exercise nonlinearities nor functional response. Frequently low level repetitive pulsing is used in conjunction with threat level pulsing because of the ease and speed of data acquisition using a free running repetitive pulse.

3.2.4.3 Accuracy. In a high level direct illumination simulator, test measurements can be performed with the following accuracy.

1. Current  $\pm 1.5$  dB = 17 percent
2. Voltage  $\pm 1.6$  dB = 20 percent
3. Electromagnetic fields  $\pm .3$  dB = 3 percent

Since the electromagnetic field components (E and H) are not mapped everywhere, field uncertainties can exceed the field measurement error. It is estimated that uncertainties are of the order of 20 percent. Thus, the transfer function errors are: for current,  $\pm 28$  percent, and for voltage,  $\pm 23$  percent. Thus, the average 1 sigma confidence interval for data taken in an EMP simulator test is  $\pm 2$  dB.

### 3.2.5 CW Radiating Test

3.2.5.1 Description. The radiated CW testing is a relatively quick and economical way to determine coupling of radiated fields to site conductors. Either a spot frequency testing or swept frequency CW testing can be used. A typical swept CW test setup is shown in Figure 3-4. Because the bandwidth of interest in EMP testing extends from 0.1 to 100 MHz, different antenna sizes or antenna loads must be used in a swept CW test.

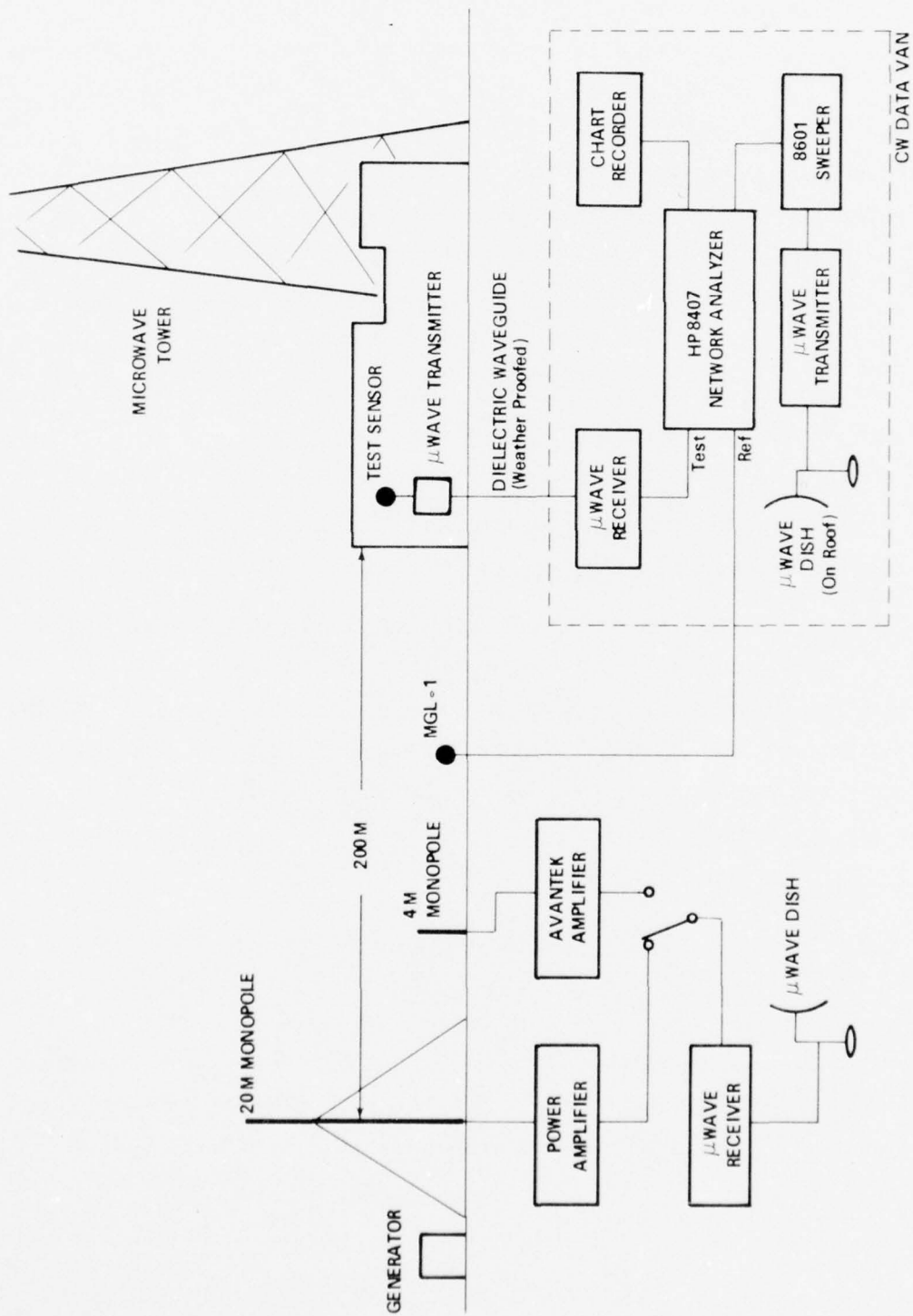


Figure 3-4. Swept CW Test Setup

3.2.5.2 Applications. The advantage of swept CW is that the amplitude portion of the transfer function can be measured directly and simply with either a spectrum analyzer or a network analyzer. With some additional care, the phase can also be gotten with a network analyzer. This technique is frequently used to measure building shielding attenuation, and to measure directly the linear behavior of the POEs. Because of its low signal levels, this technique can be used with little or no interference with site operations.

3.2.5.3 Accuracy. Radiation patterns of monopole antennas are well known. Therefore, a single reference sensor to monitor radiated signal strength will usually allow the field to be extrapolated to any point with an accuracy of  $\pm 10$  percent. Since the current and voltage measurements are known to within 17 and 20 percent, respectively, the standard deviation for the transfer functions is 20 to 23 percent, respectively. Thus, the average standard error for a 1 sigma confidence interval is @ 21 percent or 1.7 dB.

### 3.2.6 Subsystem ("Black Box") Testing

3.2.6.1 Description and Application. Subsystem direct drive testing is the direct injection of pulsed voltages and currents and to the critical interfaces of operational racks or drawers (i.e., black boxes) to measure directly the upset and failure thresholds. An excellent example of a subsystem test facility is the Air Force Weapons Laboratory Programmable Universal Direct Drive System (PUDD). A typical subsystem test setup at the PUDD is shown in Figure 3-5. It is sometimes assumed that if POEs are driven at threat level, the thresholds of the critical circuits coupled to the POEs are automatically determined. However, the synergistic effects of simultaneous excitation of all POEs plus radiated illumination is usually ignored. Thus, the critical interfaces are not necessarily excited in the same fashion they would be in a threat or radiated test. In addition, this technique is not normally applied to a statistically significant sample and does not yield the statistical spread of the threshold, i.e., the mean and standard deviation for both failure and upset. Both the mean and the spread are required for a complete accurate assessment statement. Therefore, to increase the confidence in the margin of safety, direct

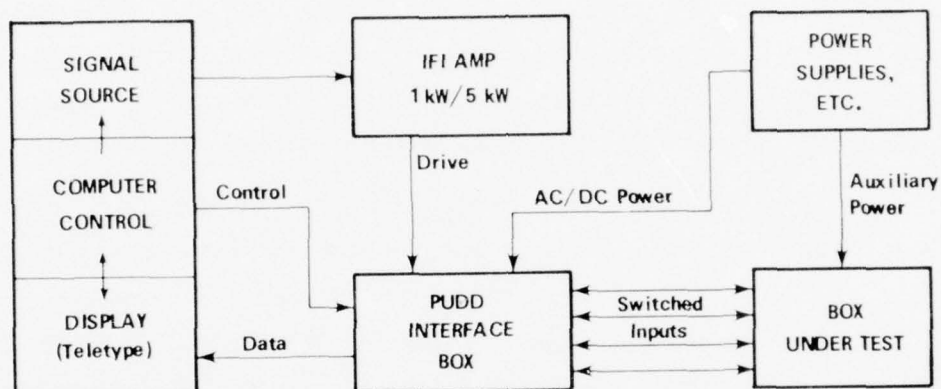


Figure 3-5. Typical Subsystem Direct Drive Test on PUDD

measurement at failure and upset threshold are required. These are normally acquired by means of subsystem or black box testing.

3.2.6.2 Data Accuracy. PUDD input pulse voltages and currents are recorded with on a Tektronix 7904 oscilloscope using 6000 series voltage and current probes. Typical accuracies for these devices are  $\pm 2$  percent for the scope and  $\pm 3$  percent for the probes.\* The measurement accuracy is therefore  $\pm 3.5$  percent or approximately .3 dB.

### 3.2.7 Scale Modeling

3.2.7.1 Description. Scale model testing is almost self explanatory. It consists of a test of a scaled down test object in a small simulator. The major shortcoming of this method is that when large test objects such as buildings are

\*Data taken from manufacturer's catalog, 1975

0 scaled large scaling factors are used. This places extreme demands on dimensional tolerances and manufacture of the scale model because test frequencies or pulse risetime and decay time must be scaled up and down, respectively. Large scale factors can place the test environment and test object response beyond the bandwidth of current state-of-the-art EMP instrumentation normally found at test facilities.

3.2.7.2 Applications. Scale modeling offers a relatively quick and economical way to increase the confidence and predicted coupling to complex external geometries. It offers an alternative to simulation or radiated CW testing in instances where these may not be possible for practical reasons such as site accessibility.

3.2.7.3 Accuracy. The limiting factor in the accuracy of scale model testing are dimensional in frequency scaling tolerances. There is limited data available on the accuracy of scale model testing. However, it is felt that scale model testing can be accomplished to within  $\pm 50$  percent or approximately 4 dB.

## SECTION 4

### ENVIRONMENTS AND SIMULATORS

#### 4.1 GENERAL

There are numerous fixed and transportable EMP simulators in the DoD EMP community. In addition to these simulators, there exists a large variety of pulsers which are used in special applications in EMP testing. The number and variety of pulsers too large to permit any comprehensive treatment.

In this Section we will present the pertinent electromagnetic characteristics of three of those transportable simulators which are considered appropriate for testing buried dispersed facilities. They are RES-I, TEMPS, and a modified SIEGE type simulator.

#### 4.2 RES-I

The Radiating EMP Simulator (RES) Program was initiated by AFWL in the spring of 1967 to develop a flyable simulator for fixed site and airplane vulnerability assessment. RES-I can be used as either a horizontally or vertically-polarized radiating antenna system. The two RES-I systems, horizontal and vertical, can be used to make coupling measurements with both horizontally and vertically polarized E-fields, (Reference 2).

##### 4.2.1 System Description

The horizontal antenna system is composed of a pulser and an inflated antenna structure, which uses a CH-47 helicopter for system mobility. The 200-foot long antenna is a fiberglass structure, which maintains its shape by inflation to 4.2 psig. This horizontal system delivers an EM pulse of at least 900 V/m at 500 meters.

The vertical antenna system uses the same pulser as above and a wire-cage antenna. It uses either CH-53 or CH-47 helicopters for system mobility. The pulser has a biconic section, with a self-breakdown switch located at the apex. It is capable of 1.75 MV output. The antenna is

approximately 200 feet long, and the pulser-antenna combination produces a pulse similar, except for polarization, to that produced by the horizontal system.

The RES-I pulser assembly consists of the following primary components: 1) power system, 2) Marx generator, 3) inductor, 4) transfer capacitor, 5) output switch, and 6) pressure vessel. Each of these components and/or subsystems is described in the following paragraphs.

#### Power System

The Marx generator is used to pulse charge a transfer capacitor through a waveshaping inductor. A simplified circuit diagram and the charging and output voltage waveforms are shown in Figure 4-1. The inductor is connected to the center conductor of the water transfer capacitor, the fast risetime element of the system. The Marx generator charges the water capacitor in about  $1.2 \mu\text{s}$ . The output switch, connecting the water capacitor to the antenna structure, is a high pressure ( $\approx 100$  psig)  $\text{SF}_6$  gap. At or near the peak charging voltage, the switch self-fires, discharging the capacitor into the antenna. Breakdown voltage is dependent upon the switch pressure.

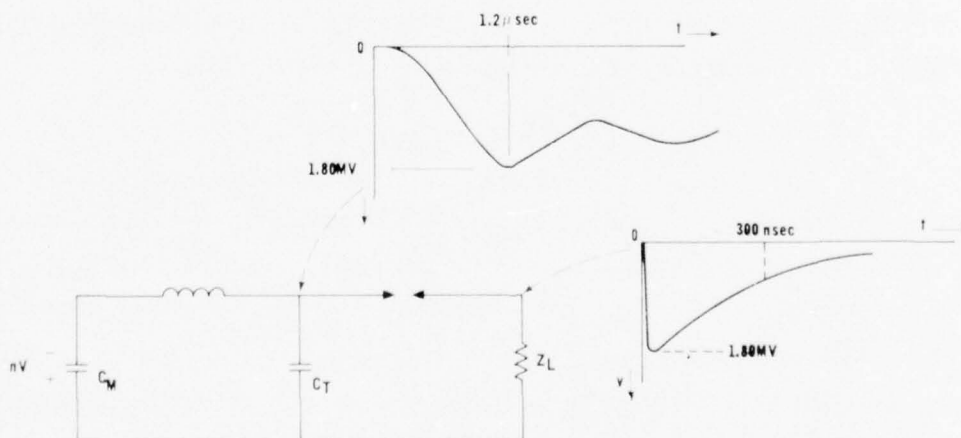


Figure 4-1. Simplified RES-I Circuit Diagram and Voltage Waveforms

#### 4.2.2 Electromagnetic Characteristics

The RES-I antenna design is based on the requirement for a radiation pattern similar to that produced by a dipole, one with symmetry about both the major and minor axes of the system. The antenna is comprised of a biconic high-frequency wave launcher and a long low-frequency radiating antenna.

##### Biconic Antenna

In the area of the pulser, the design of the antenna is biconic, as shown in Figure 4-2. This geometry radiates the high-frequencies of the system. It has been shown that the peak E-field magnitude on the equatorial plane is:

$$E_{pk} = \frac{60 V_o}{r Z_k}$$

where  $E_{pk}$  is the magnitude of the peak E-field,  $V_o$  is the driving voltage,  $r$  is the radial distance to the point of observation, and  $Z_k$  is the biconic impedance given by

$$Z_k = 120 (\ln \cot \theta_{hc}/2).$$

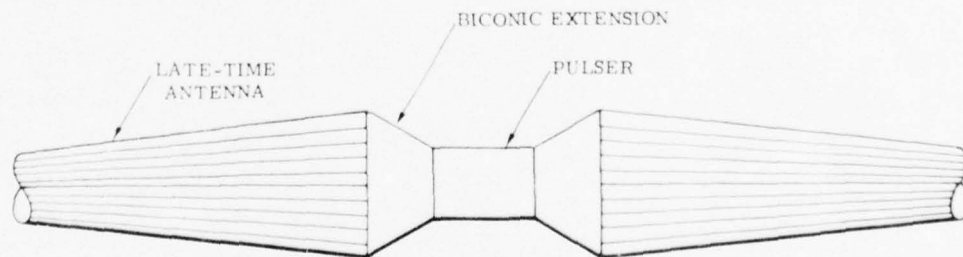


Figure 4-2. Pulser Antenna System

The value  $\theta_{hc}$  is defined in Figure 4-3. The above expressions assume the pulse risetime to be instantaneous. For risetimes that are not instantaneous the peak field is radiated if the biconic slant height exceeds a certain minimum length.

For this pulser,

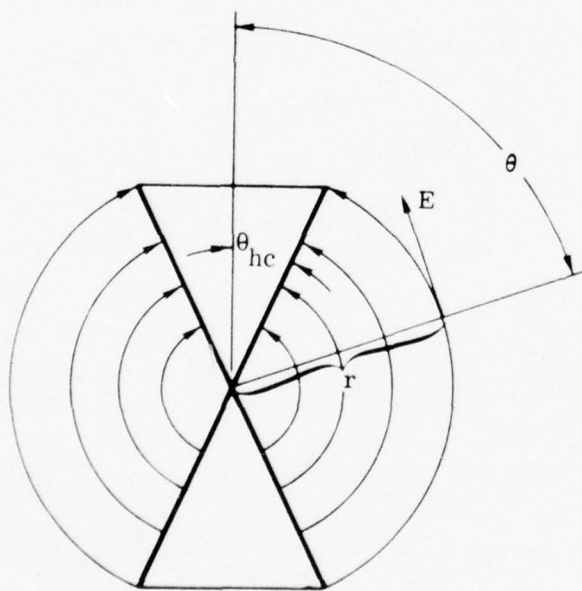
$$\theta_{hc} \approx 30 \text{ degrees.}$$

Therefore,

$$Z_k \approx 160 \Omega \text{ and}$$

$$E_{pk} \approx 1.3 \text{ kV/m at } 500\text{m}$$

(assuming the maximum  $V_o$  1.75 MV).



$$Z_k = \frac{Z_o}{\pi \sqrt{\epsilon_r}} \ln \cot \frac{\theta_{hc}}{2}$$

$$E = \frac{60 V_o}{r \sin \theta Z_k}$$

Figure 4-3. Biconic Transmission Line

Figures 4-4 and 4-5 show time and frequency domain plots of a typical RES pulse. The B sensor was located 500m from the source. The peak magnetic field is  $5 \times 10^{-6}$  tesla or an electric field of 1.5 kV/m. (The data as illustrated has been corrected for ground reflections and angle of incidence.) After peak, the slope of the radiated pulse is determined by the design of the long antenna sections. For a simple nonresistively loaded dipole antenna, the length of this pulse, beyond which undershoot occurs, is equal to the antenna half-length. For this antenna, L is 100 feet and the pulse length to the first zero crossing should be 100 ns at the equatorial plane. Since the antenna is resistively loaded, a somewhat shorter time should be anticipated. In Figure 4-5 the pulse width is about 70 ns.

For the vertical antenna system, resistors are placed on the ends of the antennas to reduce the current to zero before the initial wave arrives at these points. The radiated waveform is then shaped and damped and the outward flowing current is reduced in steps. Subsequent reflections are, however, spread in space and time.

For the horizontal antenna system, lumped resistors are located at points along the antennas. The objective here is to damp the oscillatory nature of the fat-dipole radiation.

#### 4.3 TEMPS

The TEMPS I (Transportable Electromagnetic Pulse Simulator), sponsored by the Defense Nuclear Agency, was designed and built by Physics International Company for the Harry Diamond Laboratories. The TEMPS simulates the electromagnetic environment produced by exo-atmospheric nuclear bursts. TEMPS is a complete, self-contained simulator that could be completely transported to remote sites, rapidly erected, checked out, and reliably operated to conduct EMP tests.

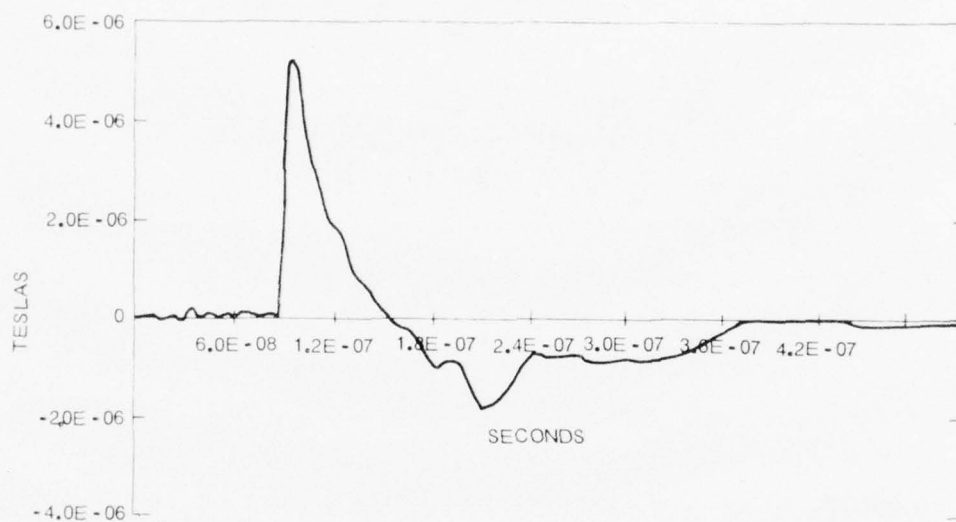


Figure 4-4. RES Pulse Time Domain

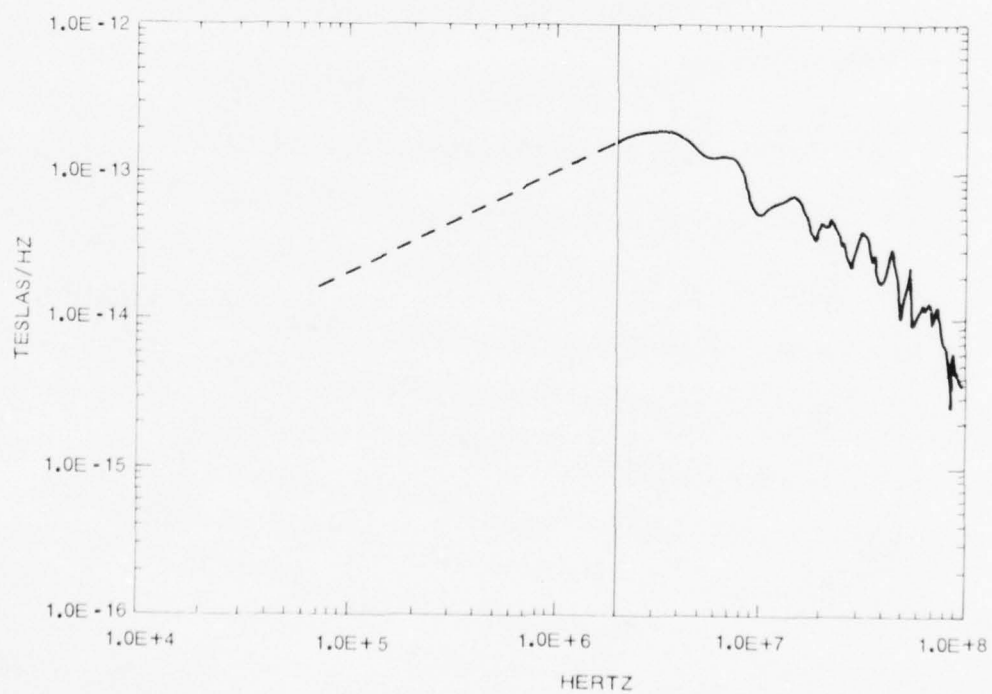


Figure 4-5. RES Pulse Frequency Domain

#### 4.3.1 System Description

The system is a synchronized bilateral Marx generator /peaking-capacitor pulser that drives the terminals of a long (300 meters) dipole antenna, positioned horizontally over earth ground at elevations of up to 20 meters. The characteristics of the electromagnetic wave launched from the system are determined by the pulser in conjunction with the antenna and its position relative to ground.

A biconical transmission line, with a characteristic impedance of 120 ohms at the center of the antenna, guides the electromagnetic wave from the small dimensions of the pulser, contained within the bicones, to the 9.2 meter diameter cylindrical wire cage dipole antenna. Each end of the antenna is terminated to ground with a resistance that approximately matches the characteristic impedance of each half of the antenna, which is viewed as an equilateral rod-to-plane transmission line to ground.

Essentially, TEMPS has three individual subsystems: the pulse generator, the antenna, and the support structure.

#### Pulser

A simplified circuit of the TEMPS generator is shown in Figure 4-6.  $C_g$  is the erected series capacity of each 35-stage Marx generator;  $L_s$  is the stray inductance of each half generator; and  $R_s$  is the sum of stray and lumped series resistance.

$$C_g = 5 \text{ nF} + 10\%$$

$$L_s = 2.15 \text{ } \mu\text{H} \pm 5\%$$

$$R_s = 13 \Omega$$

$$R_{\text{shunt}} = 1.1 \text{ k}\Omega$$

$$C_p = 1 \text{ nF} \pm 10\%$$

$$Z_A \begin{cases} \text{Initial} & = 120 \Omega \\ \text{Late time} & = 250 \Omega \text{ (for 20-meter antenna to ground spacing)} \end{cases}$$

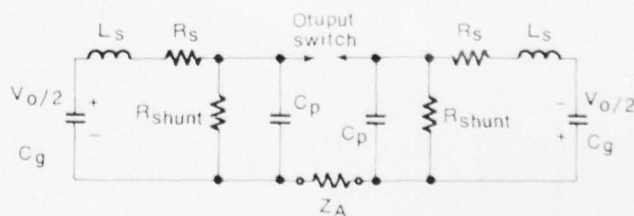


Figure 4-6. TEMPS Pulser Circuit Diagram

Typical peaking capacitor pulse charge and output voltage waveforms ( $V_o \cong 4.1$  MV) are shown in Figure 4-7. These waveforms are derived from resistive voltage divider monitors installed across the peaking capacitors on each side of the system. The monitor outputs are fed to oscilloscopes contained within screen boxes located on-board the pulser, one on each side of the system. Oscilloscope power is derived from battery/inverter sets also contained within the screen boxes.

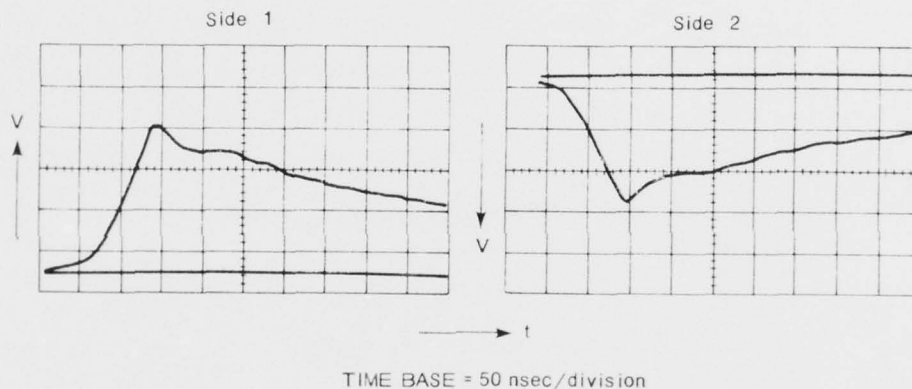


Figure 4-7. Typical Pulser Waveforms

#### Antenna

The antenna, Figure 4-8, is a cylindrical system of wires extending from each end of the pulser assembly, with associated forming hoops and assemblies, tensioning elements, and end ground terminations which launch and guide the EM wave.

The assembly forms a 120-ohm biconical radiator which launches the high-frequency early portion of the pulse with minimum distortion. The bicones are solid to a diameter of 23 feet and are tapered to a cylinder 30 feet in diameter with a conic-section wire cage.

The 30 foot diameter cylindrical wire cage dipole radiates low frequency energy. The length of this dipole can be varied in 100 meter increments to a maximum of 300 meters. Each end of the dipole is resistively terminated

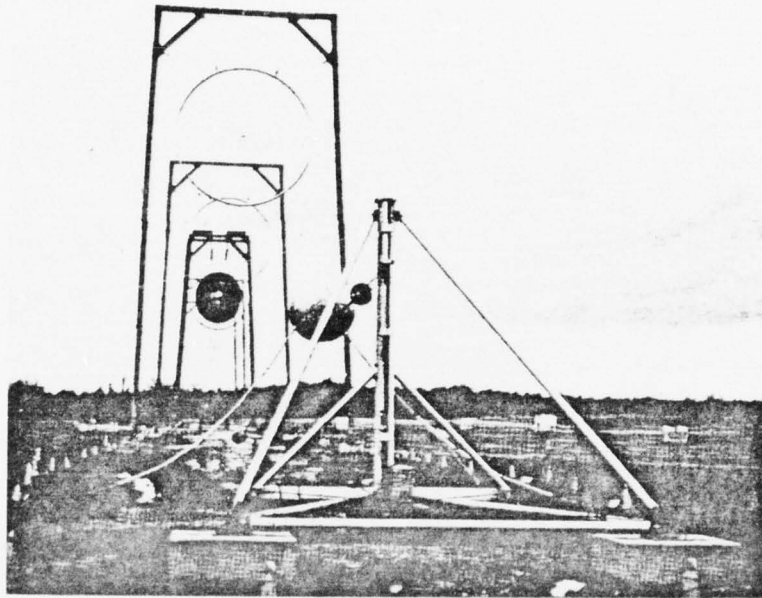


Figure 4-8. TEMPS Antenna

terminated to earth through a conical-section taper designed to maintain characteristic impedance of the dipole to the terminating resistors.

A modular, easily erectable, fiberglass structure supports the pulser, bicones, and antenna. This structure requires minimal preparation for erection and is adaptable to particular antenna configurations desired. The support structure allows the antenna height to be varied up to 20 meters and permits operation in wind velocities up to 28 mph (25 knots).

#### 4.3.2 Electromagnetic Characteristics

The TEMPS is a hybrid simulator. Peak free fields of up to 52 kV per meter can be obtained at 50 meters from the pulser. This output pulse level can be remotely adjusted over a 3:1 range. The fields are predominantly horizontally polarized.

The TEMPS is designed to produce a double exponential output pulse with less than 20 percent undershoot. Pulse risetime is adjustable (about 8 ns at most output levels). At maximum antenna length, pulse duration to first crossover is approximately 800 ns.

The broadside coverage of the TEMPS simulator for the fast rise-time peak fields is 50 meters at a distance of 50 meters from the simulator. Over this range, the peak field will vary less than 10 percent. The nominal TEMPS test area is illustrated in Figure 4-9. TEMPS can provide an angle of incidence of  $10^\circ$  to  $20^\circ$  depending on antenna height.

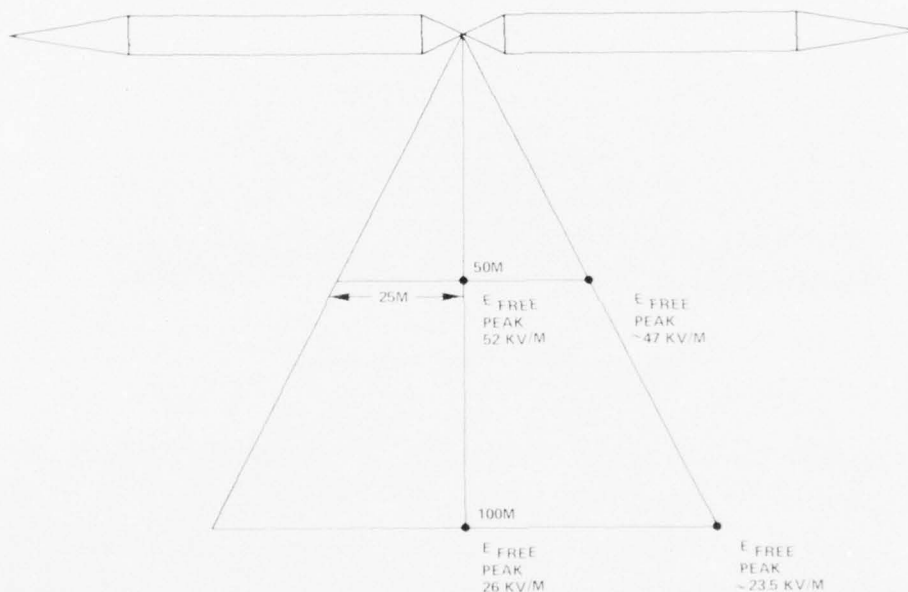


Figure 4-9. TEMPS Coverage Area

The waveform in Figure 4-10 is the time history tantential magnetic field for a probe position 50 meters horizontal from the antenna and close to earth ground. To a large extent, departure of the waveform from a perfectly smooth one arises from vertical components of antenna current (at the metal antenna hoops and termination), and gives rise to tangential magnetic fields disproportionately large compared with the incident free-field magnetic field. The spectral content is shown in Figure 4-11.

A summary of the TEMPS electromagnetic environment characteristics is given in Table 4-1.

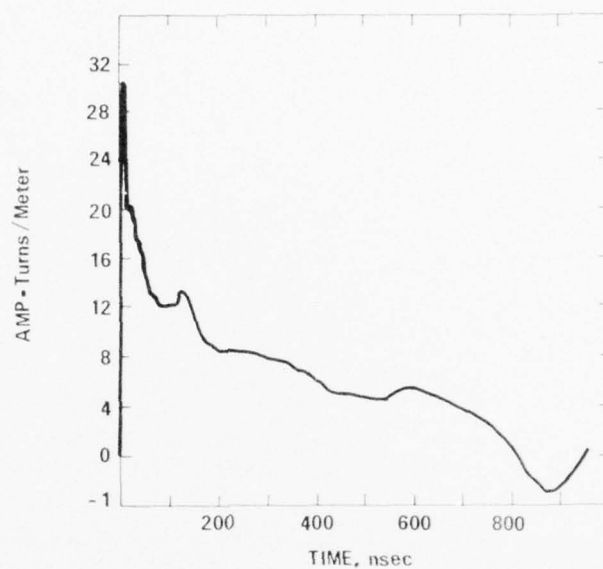


Figure 4-10. Tangential Magnetic Field at 50 Meters

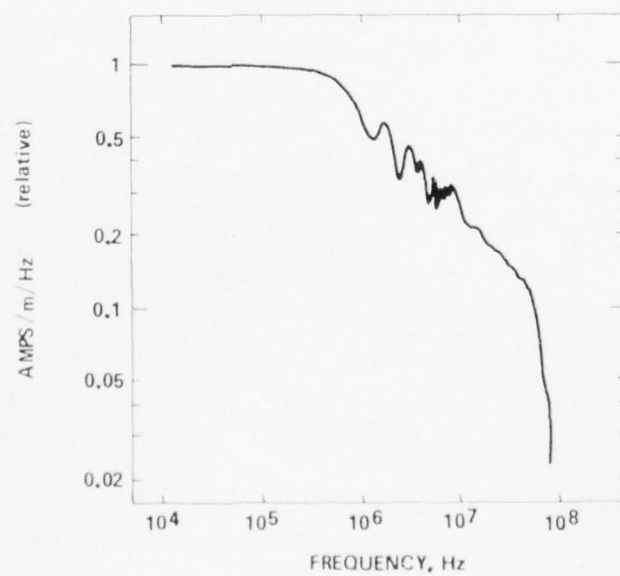


Figure 4-11. Spectral Content at TEMPS Field

Table 4-1  
Summary of TEMPS Characteristics

Pulse Shape	Double exponential
Pulse Duration	800 ns
Pulse Undershoot	20% of pulse peak
Pulse Amplitude	18 kV/m to 52 kV/m
Pulse Risettime	4 ns to 12 ns
Angle of Incidence	10° to 20° at 50m ground range
Coverage	± 25m on a line parallel to antenna axis at 50m ground range

#### 4.4 MODIFIED SIEGE

The SIEGE (Simulated Early Time Ground Environment) Simulator was initially designed specifically for testing underground facilities. It consists of an overhead array used to irradiate the surface, and a buried transmission to couple electromagnetic energy to underground facilities. See Figure 4-12. At each end of the array are four conical transmission line transition sections. At the drive end a 280kV single pulser is located. The output of the pulser is fed through a fanout box to four equal length cable thence to the four transition sections. At the termination end, four distributed resistor strings (one per transition section) are installed to minimize reflections.

The buried transmission line consists of copper clad steel rods placed deep into the ground. Each ground rod was placed in a drilled hole which had been filled with a mixture of salt water and carbon to enhance coupling into the earth.

The SIEGE mini-array was developed to support the In-Place Validation Site Survey Program. This simulator is basically a scaled SIEGE 1.2 used with SIEGE 1.2 pulser. The major characteristics of this simulator are given in Table 4-2.

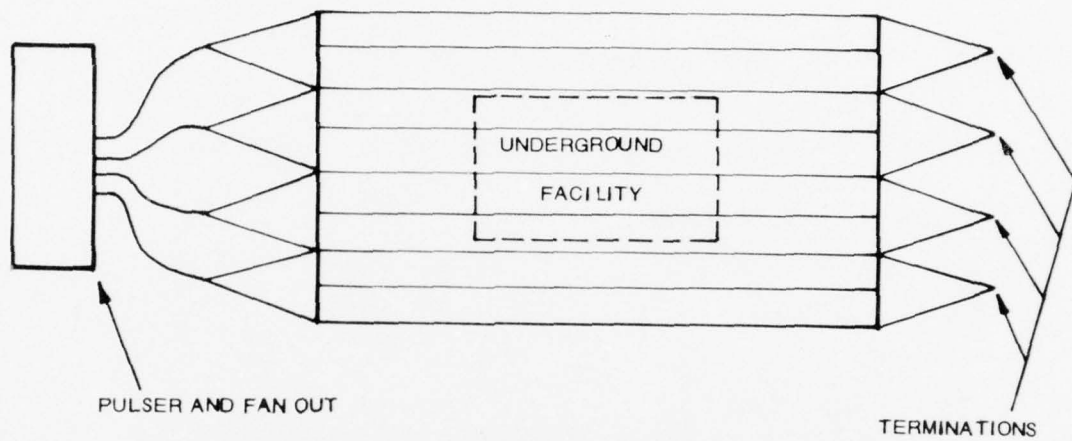


Figure 4-12 a. Plan View

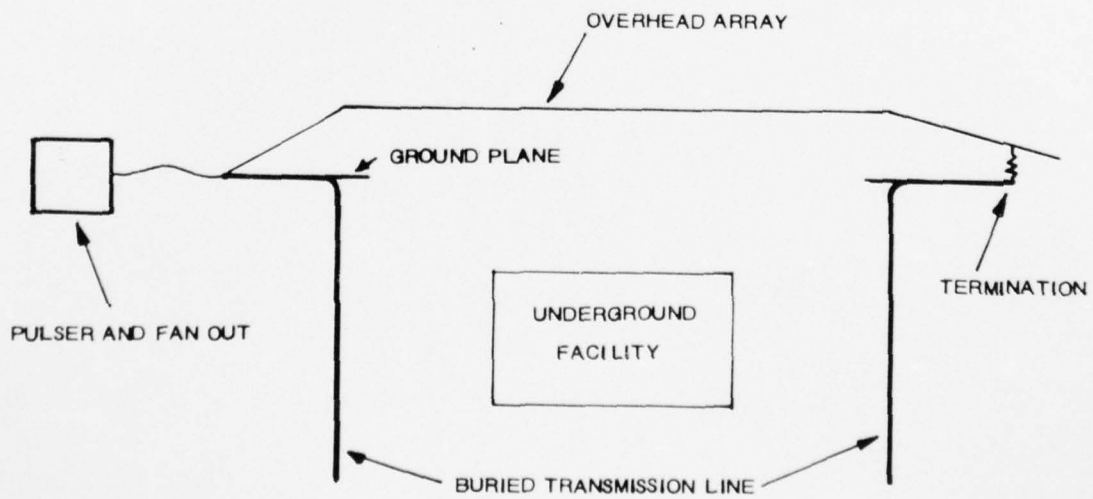


Figure 4-12 b. Side View

Figures 4-12 a. & b. Schematic Representation of SIEGE Array

Table 4-2  
Modified SIEGE Characteristics

SIEGE 1.2 pulser with high voltage mini-array (wide area illumination)

Maximum charge voltage	280 kV
Maximum field strength	50 kV/m
Risetime	30 ns
Duration	1.6 $\mu$ s
Amplitude Repeatability	
Time jitter	30 ns
Optimal load impedance	40 ohms
Number of sections	2-80 ohm sections
Height	2.4m
Illumination size	33m x 28m
Weight	10,000 pounds
Power requirements	2 110/208 3 $\phi$
Portability	Poor
Setup time	10 days
Polarization	Vertical
E/H ratio	377 ohms

To support any test of a buried C<sup>3</sup> site further modifications would be necessary. The length width and height of the coverage should be tailored to optimize exitation of each site.

For this study, an assumed design was created. This simulator has a length of 110 meters and a height of 3 meters. These dimensions were chosen to allow a test of Site 1 where the main building is 90 x 104 meters.

A hypothetical pulser was used to drive the array with a buried exponential pulse.

$$E(t) = A (e^{-4.76 \times 10^8 t} - e^{-4.76 \times 10^8 t}),$$

where A is chosen so that

$$E_{\max} = 50 \times 10^4 \text{ V/m}$$

#### 4.5 EMP TESTING WITH BURIED COILS

The idea of building magnetic coils around a buried site during construction has some appeal in that EMP testing of the very low frequency components of the EMP environment is best done this way, and secondly, installing these during the construction phase would allow subsequent testing for quality assurance with minimum interference with site operations.

Unfortunately, these advantages are outweighed by problems as we will discuss here.

In Figure 4-13 is shown a plot of the magnetic field shielding obtained with a spherical aluminum shell three feet in diameter (ref. 11). This figure illustrates the fact that there is little shielding obtained at very low frequencies. It is this observation that leads one to concern himself with low frequencies. The reader will observe that the interior field is proportional to  $\frac{1}{\sqrt{f}}$  for frequencies less than the corner frequency, that is when shield thickness = skin depth. For construction grade steel plates, the corner frequency would be only a few hundred Hertz so that only extremely low frequencies will propagate through the shields unattenuated.

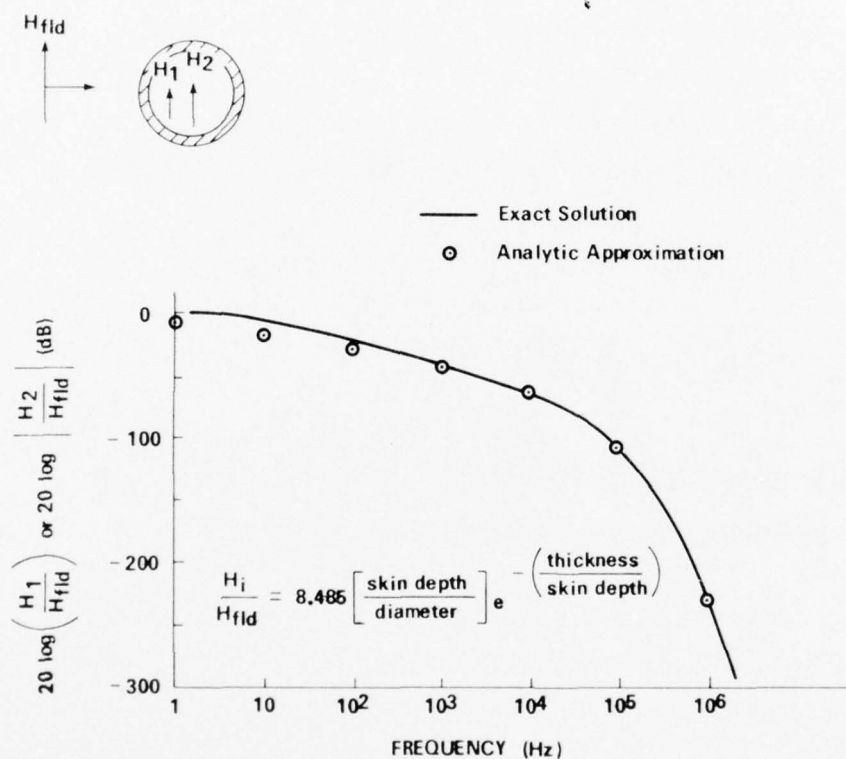


Figure 4-13. Magnetic Field Shielding of Spherical Aluminum Shell Diameter 72", Shell Thickness 1/16" (from Reference 5)

Few cases have been found where frequencies less than 100 Hz have caused either transient or permanent damage to equipment (probably because designers live with 60 cycle hum, lightning, etc.).

It is probably not worthwhile to devise a system level test to check equipment response to these frequencies.

Well, how about checking imperfect shields to higher frequencies? This is the case of most interest in the study of real systems.

Studies of cracks or apertures in shield walls or leakage through windows and doors reveal that the EM transmission through imperfections of this type increased with frequency until resonances are observed.

For typical small cracks and apertures the resonant frequencies are quite high. Because of the contemplated size of the main buried building at Site 1, large buried coils would be required. Because of inductance, dispersion, and the appearance of higher modes, it would be quite difficult and extremely impractical to drive these large coils at the required high frequencies. The conclusion is that buried coils cannot be used to generate realistic simulated EMP environments for large buried structures.

However, buried coils may be of use in detecting and locating imperfections in the shield which may develop with time. Even at frequencies well below resonance some leakage will occur at cracks and holes.

Although it would be impossible using this technique, to quantify (in dB as function of frequency) the effect of these imperfections, buried coils might be useful in locating them so that they can be repaired.

#### 4.6 COMPARISON OF SIMULATOR-INDUCED FIELDS AND CURRENTS TO ASSUMED HIGH ALTITUDE EMP-INDUCED FIELDS AND CURRENTS

##### 4.6.1 Introduction

The main concern with using EMP simulators is the problem of how well the simulators simulate the EMP fields. The objective of this section is mainly to provide some insight into this problem of coupling to buried structures. A hypothetical high altitude (HA) EMP field is compared to two simulator fields: TEMPS and a SIEGE array.

The study is organized as follows: First, we present and discuss the results for HA, TEMPS, and SIEGE arrays. These results include electromagnetic fields below the ground, and currents on cables which are either buried or elevated. Next, we present the same data on a one-to-one basis for direct comparison of HA, TEMPS, and SIEGE results. Next, we present results for currents on towers, and finally, we present the conclusions.

#### 4.6.2 Results for HA Excitation

This section provides surface and underground fields and cable currents for a high altitude EMP excitation.

The HA fields chosen have a double exponential waveform (ref. 2). Two cases are chosen for analysis and are summarized in Table 4-3. Case 1 maximizes the total horizontal electric field ( $E_H$ ), and Case 2 maximizes the total vertical electric field ( $E_V$ ). It should be noted that these are different from the vertically polarized ( $E_{VP}$ ) and horizontally polarized ( $E_{HP}$ ) components, as will now be discussed.

Figure 4-14 illustrates the geometry. The total plane wave electric field  $\vec{E}$ , incident on the earth, is shown traveling in the direction of propagation  $\hat{k}$ , which makes an angle  $\theta$  with respect to the local vertical. The plane of incidence is defined as the plane containing  $\hat{k}$  and the normal to the earth's surface. The total electric field  $\vec{E}$  can be broken up into components in the plane of incidence and perpendicular to the plane of incidence. These components will be referred to as the vertically polarized part ( $E_{VP}$ ) and the horizontally polarized part ( $E_{HP}$ ), each of which has a different reflection and transmission coefficient (ref. 6).

Table 4-3  
HA Environments

- Double Exponential Plane Wave Pulse with  $E_{\max} = 50 \text{ kV/m}$
- Two cases are chosen to maximize horizontal and vertical electric fields

1.	$A_z = 135^\circ$	$E_{VP} = .43 E_{\max}$
	$\theta = 26^\circ$	$E_{HP} = .92 E_{\max}$
	$\psi = 64.8^\circ$	
	$E_h = E_{\max}$	
	$E_v = .19 E_{\max}$	
	$ E  = 1.02 E_{\max}$	
2.	$A_z = 90^\circ$	$E_{VP} = .68 E_{\max}$
	$\theta = 26^\circ$	$E_{HP} = .63 E_{\max}$
	$\psi = 42.6^\circ$	
	$E_h = .88 E_{\max}$	
	$E_v = .30 E_{\max}$	
	$ E  = .93 E_{\max}$	

where:

$E_{\max}$  is maximum electric field

$A_z$  is angle of arrival from true north

$\theta$  is angle of arrival from local vertical

$\psi$  is angle between the E vector and  $E_{VP}$  (polarization angle)

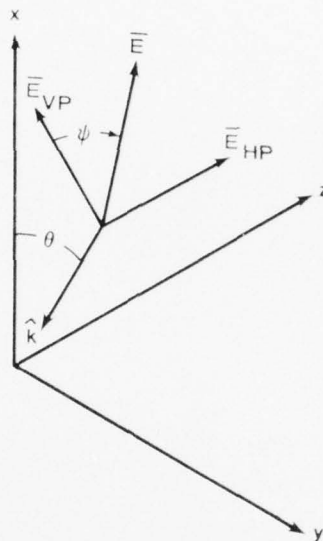


Figure 4-14. Relationship of Incident Total  $E$  to Vertically Polarized ( $E_{VP}$ ) and Horizontally Polarized ( $E_{HP}$ ) Components

The total electric field  $E$  makes an angle  $\theta$  with respect to the plane of incidence such that

$$E_{VP} = |E| \cos \psi$$

$$E_{HP} = |E| \sin \psi$$

Simple geometry shows that

$$E_H = |E| \sqrt{\sin^2 \psi + \cos^2 \psi \cos^2 \theta}$$

$$E_V = |E| \cos \psi \sin \theta,$$

from which we get

$$\tan^2 \psi = \left( \frac{E_H}{E_V} \right)^2 \sin^2 \psi - \cos^2 \theta \quad (1)$$

$$|E| = \frac{E_V}{\cos \psi \sin \theta}, = \frac{E_V}{\sqrt{\sin^2 \psi + \cos^2 \psi \cos^2 \theta}} = \sqrt{E_H^2 + E_V^2}. \quad (2)$$

According to the coordinate system of Figure 4-14, the vector forms of the horizontally and vertically polarized incident fields are given by

$$\bar{E}_{HP\_INC} = E_{HP} \hat{U}_z \quad (3)$$

$$\bar{H}_{VP\_INC} = \left( \frac{E_{VP}}{\eta_o} \right) (-\hat{U}_z) \quad (4)$$

where  $\eta_o = 377$  ohms,  $\hat{U}_z$  is the unit vector in the z-direction.

The discussion will focus upon the underground electric fields at a depth d, according to

$$\bar{E}_{HP\_UG} = (E_{HP}) (T_{HP}) e^{-jK_g d} \hat{U}_z \quad (5)$$

$$\bar{E}_{VP\_UG} = -\eta_g \left( \frac{E_{VP}}{\eta_o} \right) (T_{VP}) e^{-jK_g d} \hat{U}_y \quad (6)$$

where  $k_g$  and  $\eta_g$  are the complex propagation constant and wave impedance in the earth, and  $T_{HP}$  and  $T_{VP}$  are the plane wave transmission coefficients as determined from Stratton (Reference 6, Stratton, J.A., Electromagnetic Theory). Because of the large earth conductivity, the wave propagates very nearly vertically into the ground.

The ground permittivity and conductivity are a function of frequency and water content according to the data of Scott (ref. 4) as discussed by Longmire (Reference 3). An average soil of 10% water content is used for these calculations.

The total underground electric field vector is the vector sum of the vertically polarized and horizontally polarized component parts and forms an angle  $\alpha$  with the y axis as shown in Figure 4-15.

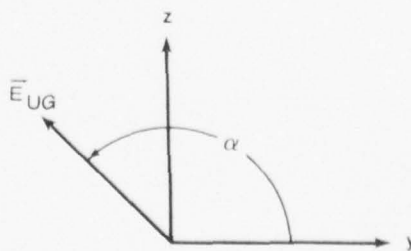


Figure 4-15. Definition of Angle  $\alpha$ , Showing the Magnitude of the Underground Electric Field Vector  $E$  and its angle With Respect to the y Axis

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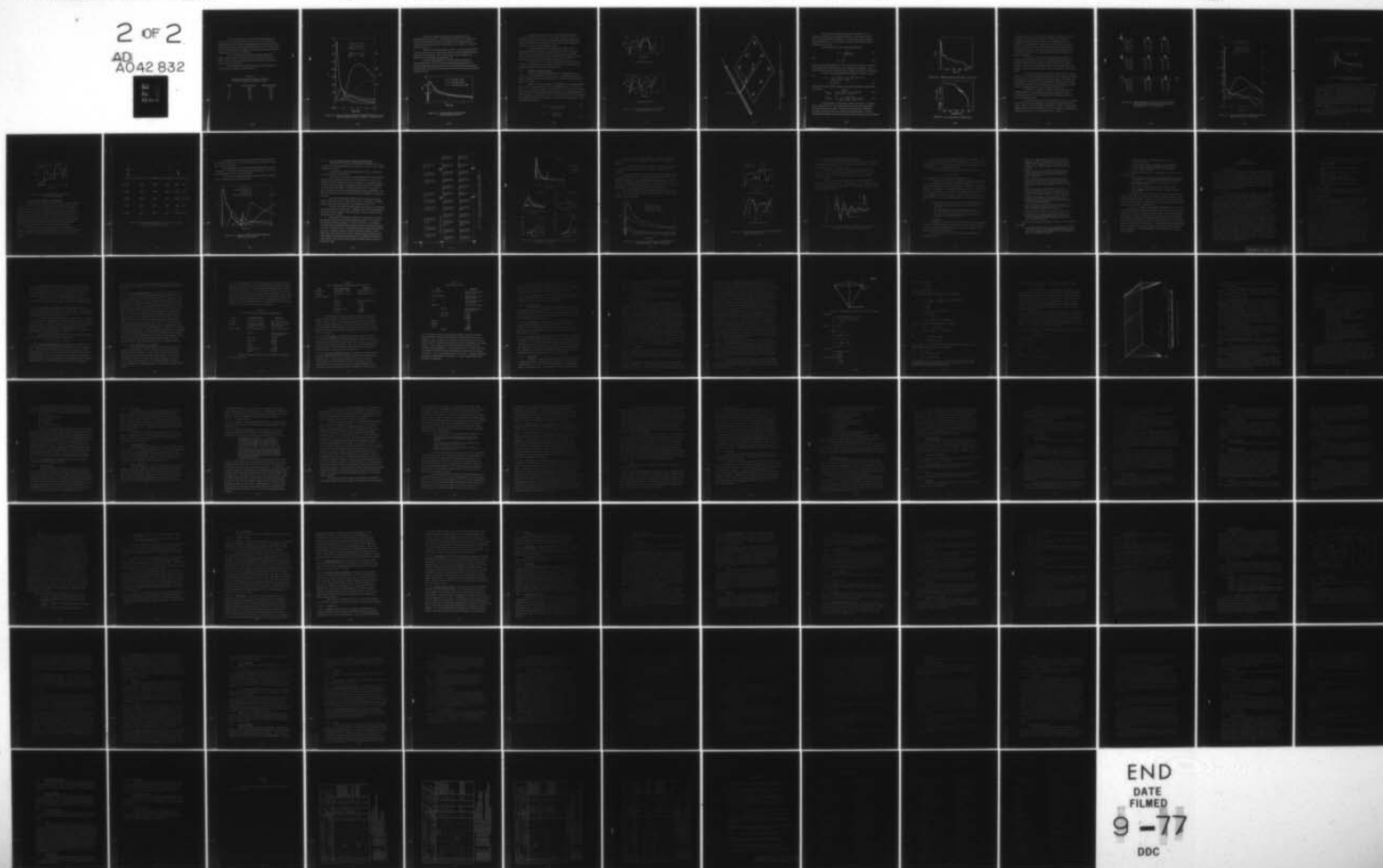
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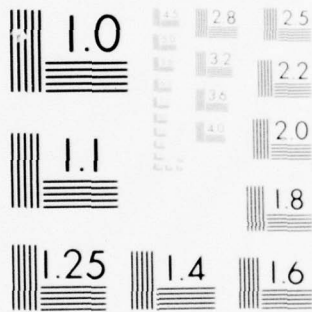
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Table 4-4 summarizes the peak electric field amplitude and the angle  $\alpha$  as a function of depth for two cases. It is noted that there is approximately 35 dB attenuation in amplitude between 1 and 20 meter depths. The peak amplitude does not attenuate uniformly as a function of depth. This is because the fields nearer the surface contain higher frequencies which are attenuated more than the low frequencies.

This is evident in the fact that the waveshape changes with depth as shown in Figure 4-16 which shows the total electric field for Case 1. The rise time at 20 meters is greater than 800 ns, and the rise time at 1 meter is about 20 ns.

It is noted that the variation with depth is quite comparable to the results given in Chapter 11 of reference 12.

Table 4-4  
Summary of Peak Electric Fields as a Function  
Of Depth and Angle  $\alpha$  for HA Cases 1 and 2

Depth	Case 1 ( $\alpha \cong 117^\circ$ )	Case 2 ( $\alpha \cong 130^\circ$ )
1	7500	7000
5	1460	1380
10	510	482
15	238	226
20	129	123

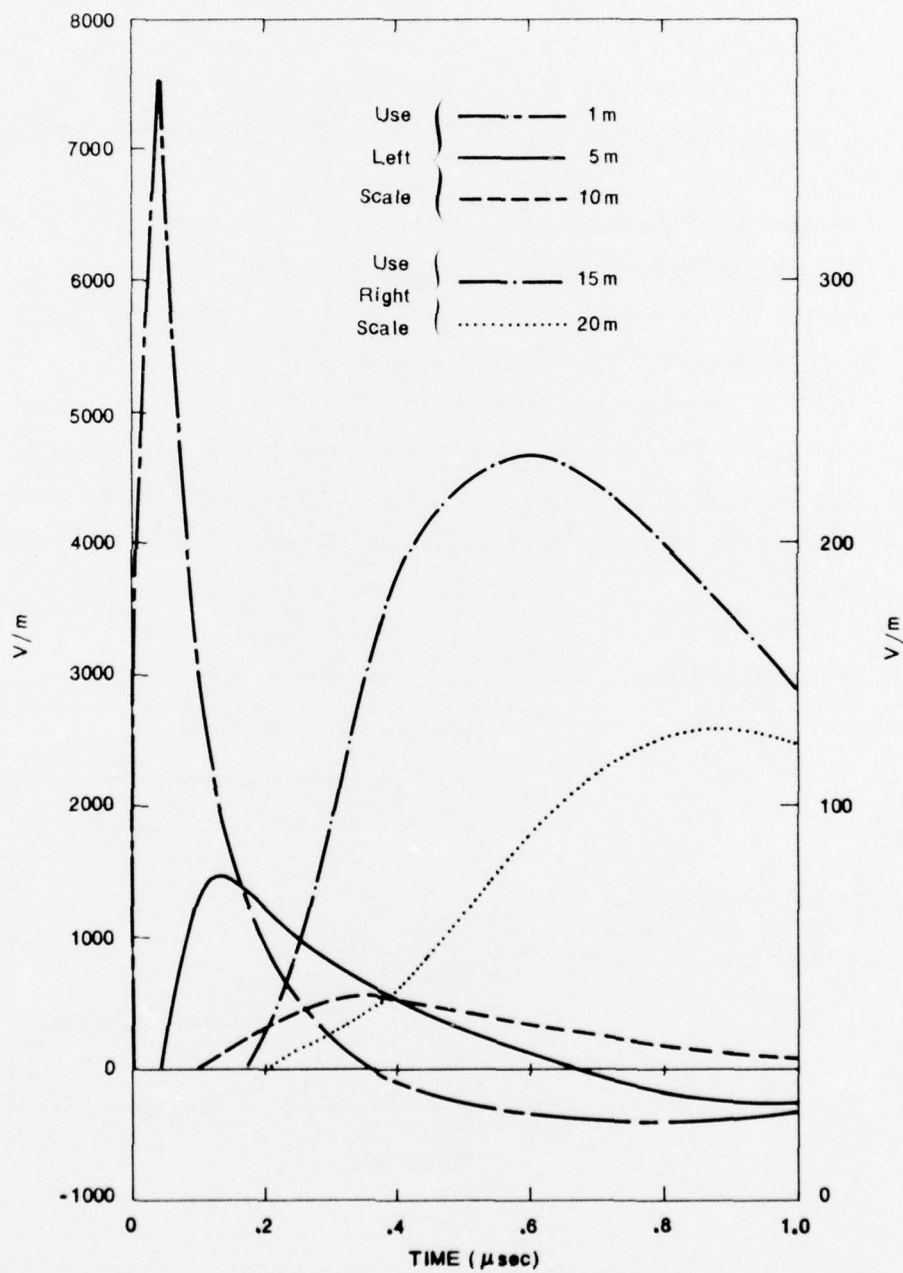


Figure 4-16. Electric Field as a Function of Depth for HA Case 1. Note Different Amplitude Scales for Depths of 15 and 20 Meters

Currents on a buried cable were also calculated for the HA environment Case 1 and Case 2. The methodology used is that of reference 7. The cable is positioned such that it is excited by the horizontally polarized component of the underground field, and this lies in the z direction. The water content is again 10%.

Figure 4-17 shows the results for Case 1. Curves are presented for the short circuit current on the end of the cable for a 50m and 100m length cable, at depths of 1 and 5 meters. The results for Case 2 can be obtained from Figure 4-17 by multiplying the amplitude by .68.

The curves show that there is very little difference between a 100m and 50m cable. This is because the cable propagation constant is so lossy that signals reflected from one end of the cable are sufficiently attenuated by the time they reach the other end that they are masked by the locally generated signals at that end.

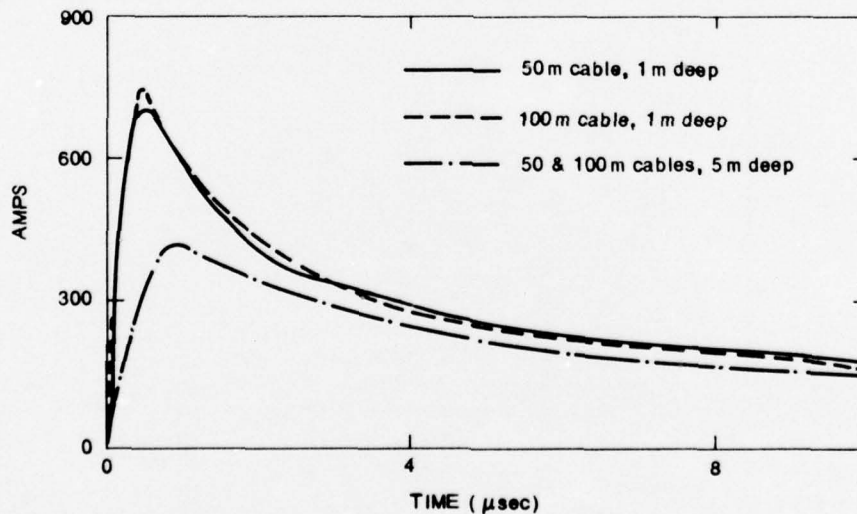


Figure 4-17. HA Excited Short Circuit Buried Cable Currents for Case 1

Calculations were also done of currents and voltages induced on a cable 10 meters above the earth. The cable is modeled as a wire over a perfect ground plane except that the exciting fields are obtained by the HA fields incident upon an earth having 10% water content. Simple TEM transmission line theory is used to obtain the solution.

The transmission line is excited by the free space electric fields and the fields reflected from the earth delayed in time. The electric fields used are the horizontal electric field along the wire length and the vertical electric fields in the ends. The transmission line is loaded at each end with a 10 meter length of wire having an inductance of 13.2  $\mu$ H.

The cable is in the z direction of Figure 4-14, with the right end referring to the end pointing in the negative z direction. The results for the current for both HA cases are shown in Figure 4-18.

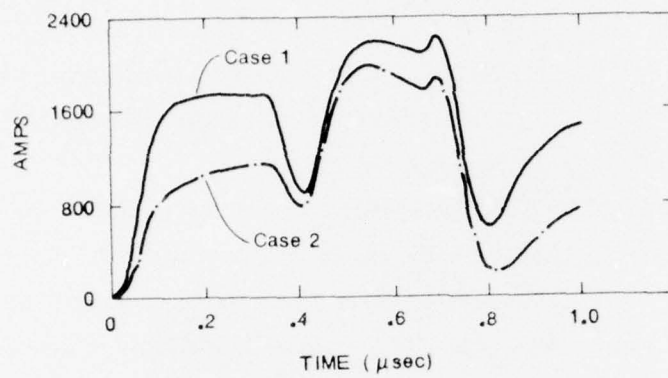
#### 4.6.3 Results for TEMPS Excitation

The electromagnetic fields produced by a TEMPS antenna are much more complicated than the HA plane waves. For TEMPS, the amplitude, angle of incidence, and the wave polarization are a function of position, whereas they are not for HA.

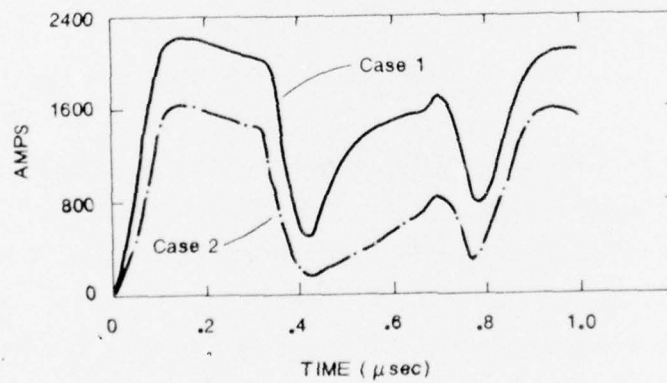
Figure 4-19 shows an oblique view of TEMPS. The coordinate system is the same as that used in Figure 4-14. The TEMPS antenna is on the z axis at  $y = x = 0$ . It is 20 meters above an earth with 10% water content. The electric fields in the ground are calculated at nine locations shown in one quadrant of the view of the figure. If one draws a vector from the origin at (0,0,0) to another point (x,y,z) where the fields are to be defined, it is useful to define the angles  $\beta$  and  $\phi$  according to the following:

$$\cos \beta = \frac{z}{\sqrt{x^2 + y^2 + z^2}} \quad (7)$$

$$\cos \phi = \frac{y}{\sqrt{x^2 + y^2}} \quad (8)$$



a) CURRENT ON LEFT END



b) CURRENT ON RIGHT END

Figure 4-18. HA Induced Current on a 100m Long Overhead Cable for Cases 1 and 2

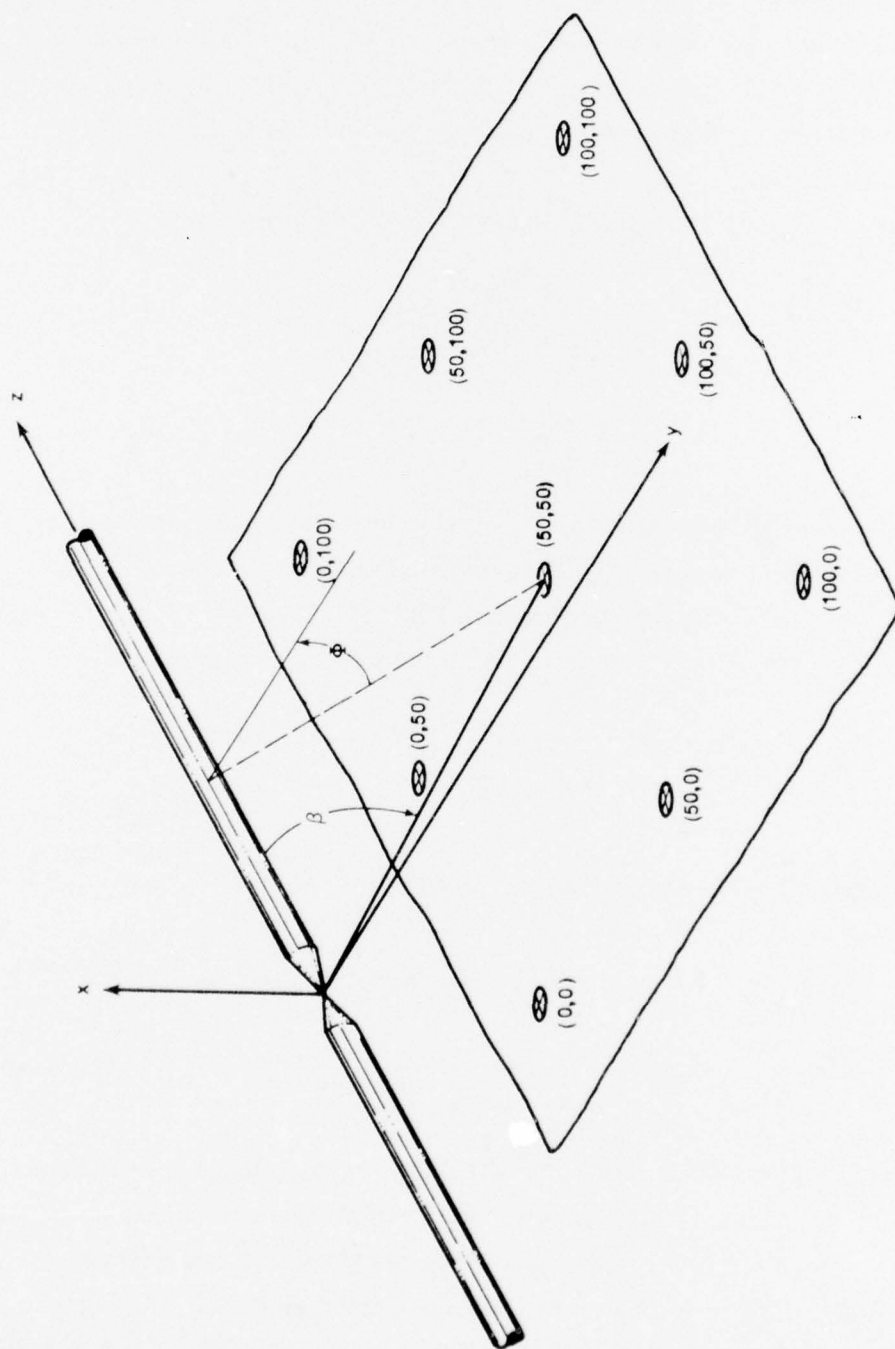


Figure 4-19. Three-Dimensional View of TEMPS Showing  $(y, z)$  Coordinates Where Underground Fields are Calculated

The fields are found from the formulas of Jordon (ref. 5) for fields near a dipole and are expanded in a power series to obtain the fields before reflection from the ends take place. This is equivalent to making the antenna infinitely long, or else having a long antenna with perfectly matched terminations on each end.

The resultant total electric and magnetic fields are

$$E_t = \frac{V_o}{\psi \sqrt{x^2 + y^2}} \quad (9)$$

and

$$H_\phi = \frac{-E_t}{Z_o} \quad (10)$$

where  $V_o$  is the pulser voltage and  $\psi$  is a constant, and are chosen to normalize the incident electric field to 50 kV/m at the earth at the coordinate  $y = 50$  m.

The field and its spectral content are shown in Figure 4-20 and 4-21, respectively.

The unit vector  $\hat{U}_p$  perpendicular to the plane of incidence is given

by

$$\hat{U}_p = \frac{1}{\sqrt{\sin^2 \beta \cos^2 \phi + \cos^2 \beta}} \left[ \hat{U}_z (\sin \beta \cos \phi) - \hat{U}_y (\cos \beta) \right] \quad (11)$$

Then the incident horizontally polarized and vertically polarized incident fields are given by

$$\bar{E}_{HP\text{INC}} = \frac{E_t \cos \phi}{(\sin^2 \beta \cos^2 \phi + \cos^2 \beta)^{1/2}} \hat{U}_p \quad (12)$$

$$\bar{H}_{VP\text{INC}} = \frac{-E_t}{\eta_o} \frac{\sin \phi \cos \beta}{(\sin^2 \beta \cos^2 \phi + \cos^2 \beta)^{1/2}} \hat{U}_p \quad (13)$$

An approximation is made that the plane wave reflection coefficients for the earth can be used. The fields below the ground are then calculated in an analogous manner as for HA. The plane wave transmission coefficients are used to obtain the fields at the surface for both polarizations. They are attenuated exponentially according to the depth and both polarizations are then added

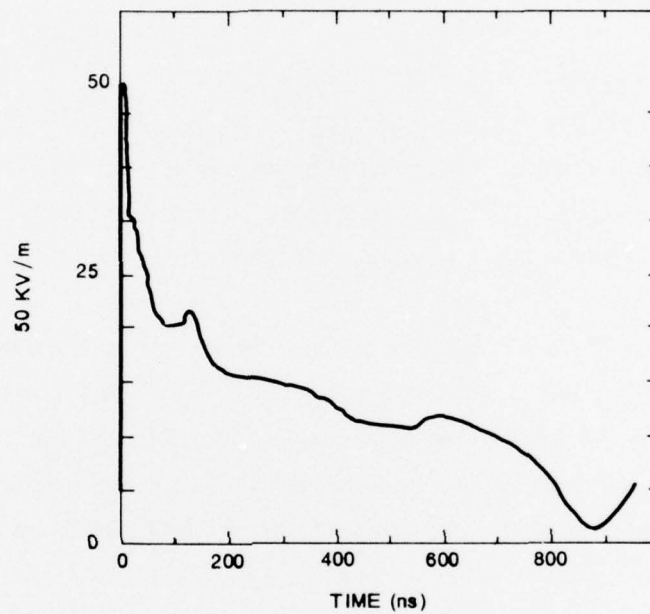


Figure 4-20. TEMPS Incident Electric Field at (-20, 50, 0)

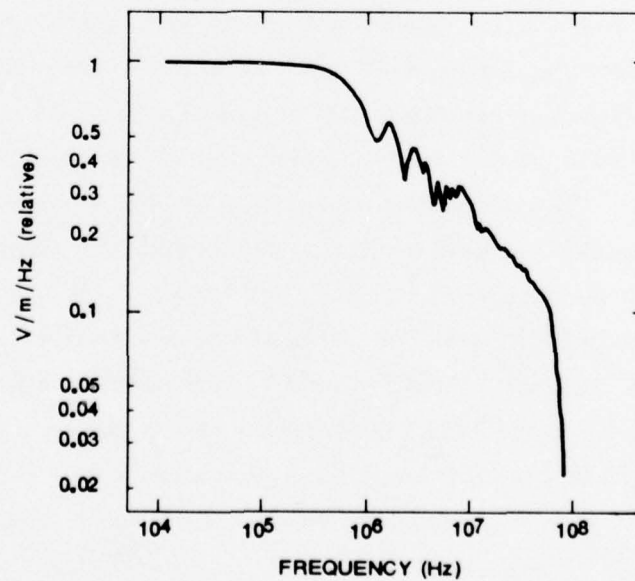


Figure 4-21. Spectral Content of TEMPS Field

vectorially to give a total electric field magnitude in the earth and an angle  $\alpha$  (Figure 4-15) with respect to the y axis. Because the vertically and horizontally polarized reflection coefficients are different functions of frequency, the waveshapes in the ground for the components are generally different. However, because of high earth conductivity, the waveshapes are very nearly the same. The angle  $\alpha$  is taken to be the arctangent of the ratio of the z component to the y component at the time in which the total electric field peaks.

Figure 4-22 is a plan view of the quadrant of the TEMPS for which fields are calculated, and it shows the peak value and the angle  $\alpha$  of the electric fields below the ground as a function of depth and horizontal position. Again, the total attenuation from 1m to 20m is about 37 dB. The variation of the field amplitudes for the test area considered is on the order of 29 dB.

The waveshape variation as a function of depth at (50,0) is shown in Figure 4-23. Note the different amplitude scales for the three lowest depths. The rise time changes considerably as a function of depth. Fortunately, the waveshape does not appear to change significantly as a function of horizontal position and the curves of Figure 4-23 apply to the other horizontal positions as well, if the amplitudes are scaled according to Figure 4-22.

Calculations of currents on a buried cable were also done for TEMPS excitation. The methodology is the same as that used for HA, except that now the electric field excitation varies spatially along the line in both amplitude and phase.

The cable is buried in the earth and parallel to the z axis. Because the results for HA showed essentially no difference between 50m and 100m cables, and the fact that the TEMPS and HA fields are similar in shape underground, results will be presented only for a 50 meter cable. It is buried in the earth and is located at  $y = 50$ , and runs between  $z = 0$  and  $z = 50$ .

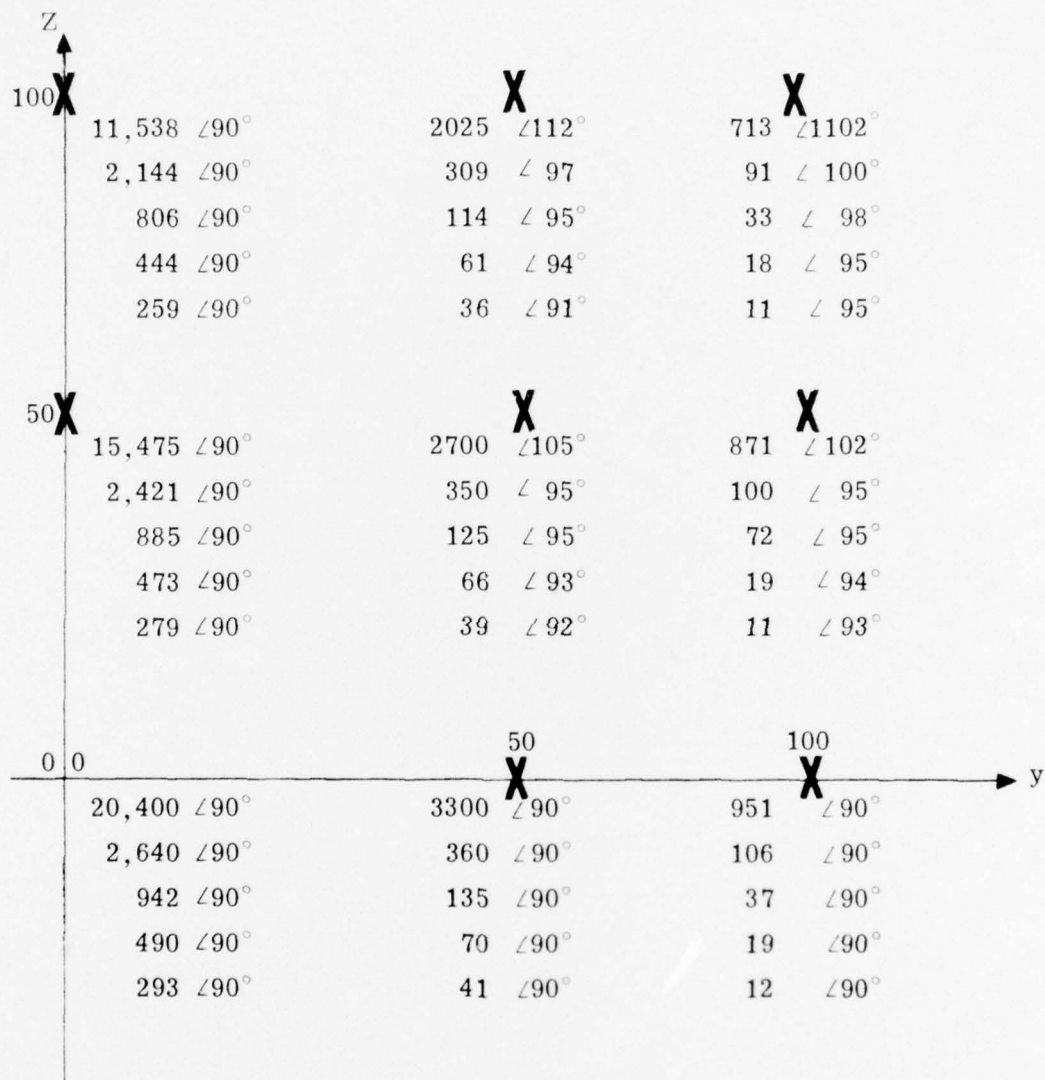


Figure 4-22. Amplitude Variation of TEMPS Underground Electric Fields with Depth and Horizontal Location. Fields Are at Depth of 1, 5, 10, 15 and 20 m

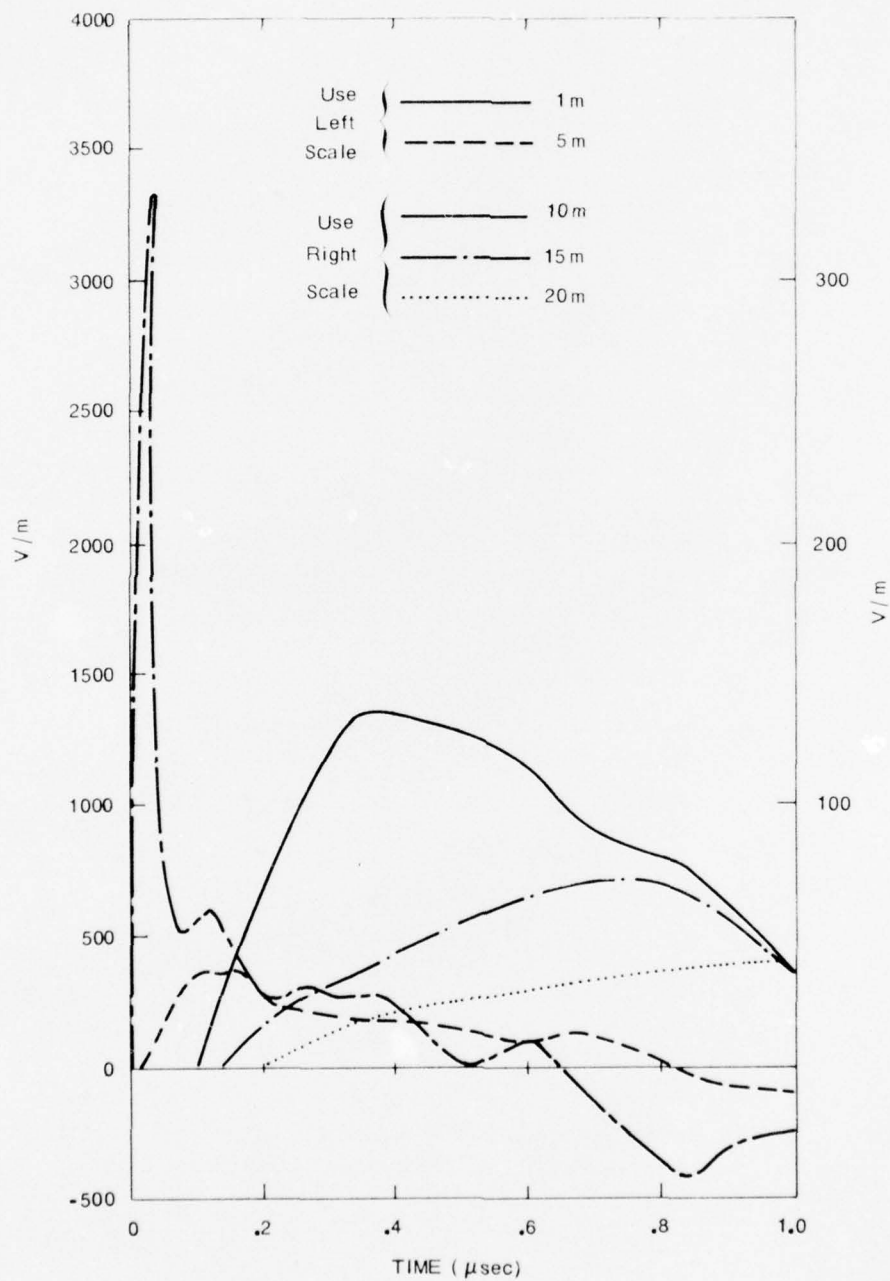


Figure 4-23. Waveshape Variation of TEMPS Underground Electric Field at (50, 0) with Depth

The results for the short circuit currents at two burial depths are shown in Figure 4-24, for the current on the end of the cable nearest the y axis ( $z = 0$ ).

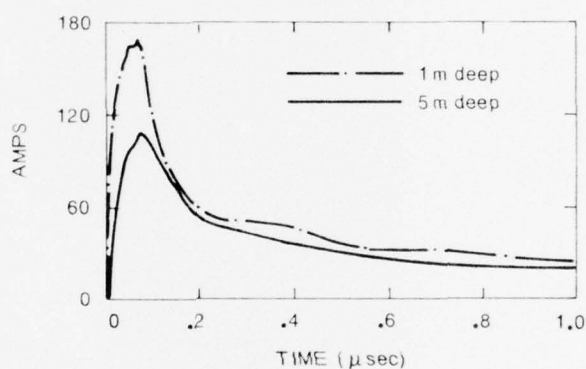


Figure 4-24. Short Circuit Current on Buried Cables Excited by TEMPS

The currents on an elevated cable are also calculated for the TEMPS environment. The cable and methodology used are the same as for HA. The cable is parallel to the z axis, 10 meters above the earth, and running from  $z = 0$  to  $z = 100$ m at a y coordinate of 59m. The excitation in this case is quite complex. The cable is excited along its length by the tangential electric field ( $E_z$ ) and on the ends by the vertical electric field ( $E_x$ ). Both involve direct waves from the antenna and waves reflected from the earth delayed in time. Both the direct and earth reflected waves vary along the cable length in both magnitude and phase.

Figure 15 shows the currents calculated on both ends of a 100m cable. It is to be noted that the response at the end at  $z = 100$  is delayed with respect to that at the end at  $z = 0$ .

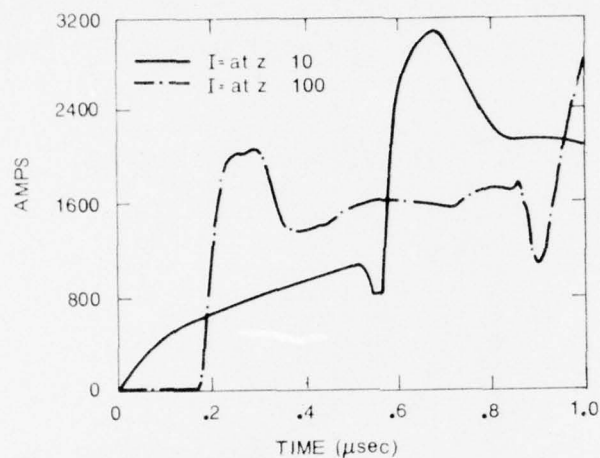


Figure 4-25. Currents on 100m Long Overhead Cable Excited by TEMPS

#### 4.6.4 Underground Fields Induced by a SIEGE Array

A study was done to predict underground fields induced by a SIEGE type of array. The array is two dimensional as illustrated in Figure 4-26. The array consists of a perfect conductor 3m above the ground and 110m long. It is terminated in each end by a resistor which provides a wave impedance of 377 ohms which will perfectly match the TEM waves in the transmission line formed by the earth and the upper plate. The pulser is located in the left end of the line as shown. Calculations were performed with the pulser providing either a step or double exponential waveshape, but the double exponential waveshape provided the best comparisons to the HA environments.

The analysis was done in the time domain with a 2-D finite-difference computer solution of Maxwell's equations. The ground permittivities were  $\epsilon_r = 100$  and  $\sigma = .01$  mho/m, which roughly corresponds to 10% water content.

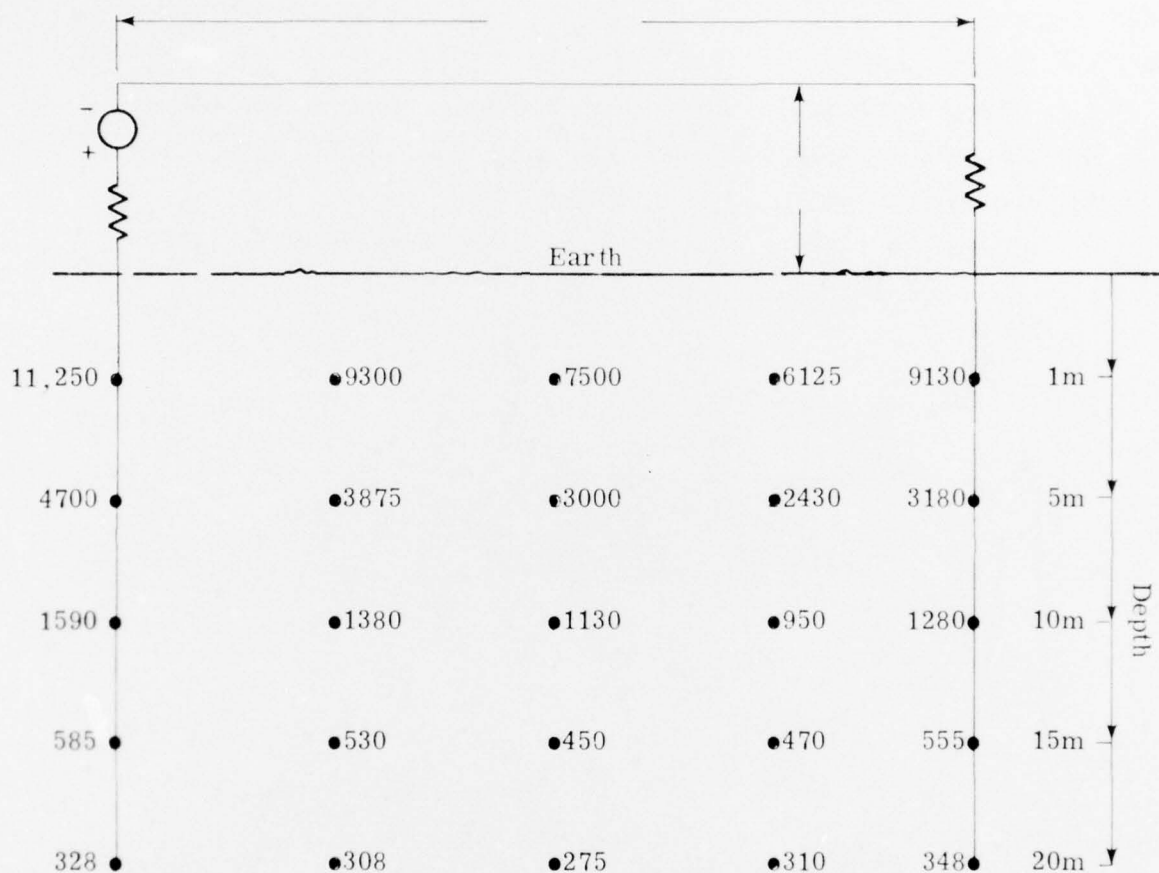


Figure 4-26. Two-Dimensional SIEGE Array Geometry and Spatial Variation of Peak Electric Fields

The spatial variation of horizontal electric field peak amplitude is also shown in Figure 4-26. It is noted that the fields vary horizontally about 50% over the region shown.

The waveshapes also vary slightly with horizontal position, but not significantly. The variation with depth is shown in Figure 4-27. Again, the risetime greatly increases at the lower depths.

Because it does not appear practical to excite cables with a SIEGE array, no cable calculations were performed.

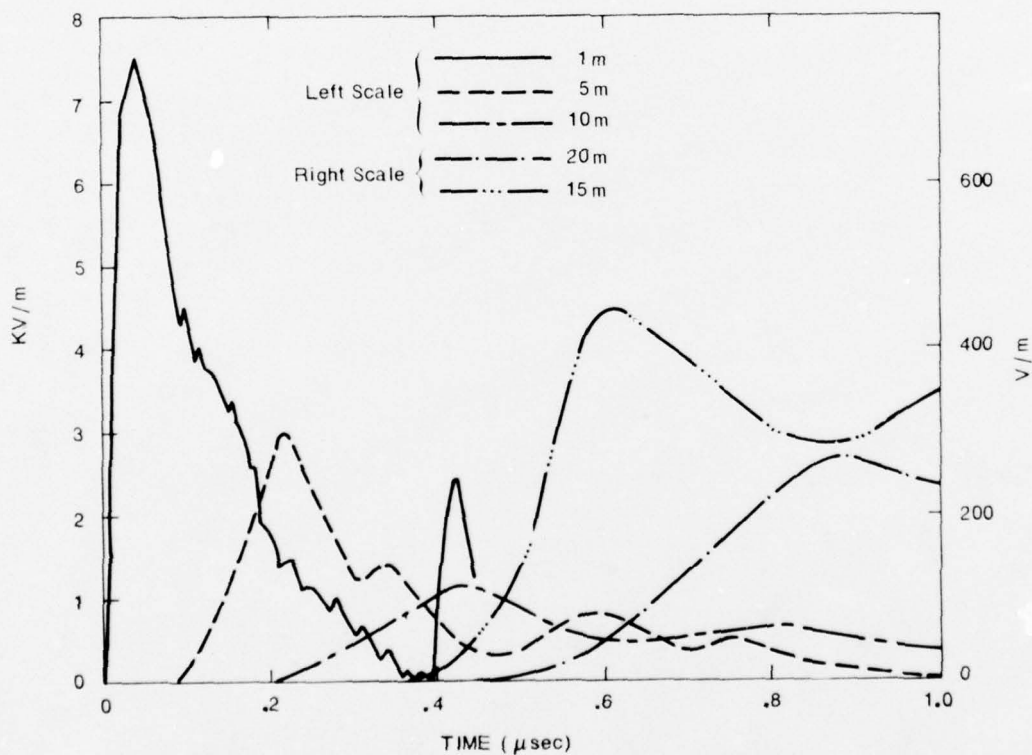


Figure 4-27. Variation of SIEGE Field Waveshapes with Depth at Center of Array

#### 4.6.5 Direct Comparison of HA, TEMPS, and SIEGE Results

The objective of this section is to provide a convenient one-to-one comparison of the underground field and cable current results for HA, TEMPS, and SIEGE excitations.

The comparison of the underground electric fields is summarized by means of Figures 4-28 and 4-29.

Figure 4-28 is a summary of the peak amplitudes of the underground electric fields for the three excitations. The view shown is a top view of a TEMPS and SIEGE superimposed on top of each other. It is assumed that the facility to be tested would be located directly under the center of the TEMPS or in the center of the SIEGE. The SIEGE is assumed to be long enough in the y axis direction so that the 2D finite-difference analysis would apply. The HA fields, of course, do not vary with position but are included for convenient reference.

The figure shows that the TEMPS variation is much greater than SIEGE for the same test area. Over this test area, for example, the TEMPS field at 5 meters down varies 23 dB, while the SIEGE varies .5 dB.

The figure shows that the SIEGE fields at the center are not attenuated with depth as much as the other fields. TEMPS and HA are attenuated approximately 35 dB between depths of one and 20 meters, while the SIEGE fields are attenuated only about 29 dB.

One may question whether the difference in attenuation is caused by the different formulation of constitutive parameters and/or if it is caused by the difference between simulations. In order to check this, a computation was made of the HA underground fields using the same constitutive parameters as used in the SIEGE analysis. The attenuation between 1 meter and 20 meters was 31 dB. Inspection of Figure 4-26 reveals that the attenuation for the SIEGE fields varies between 31 and 26 dB, depending upon horizontal position. It thus appears that the different formulation of the constitutive parameters is on the order of 4 dB, but the variation within the SIEGE simulator itself is on the order of 5 dB.



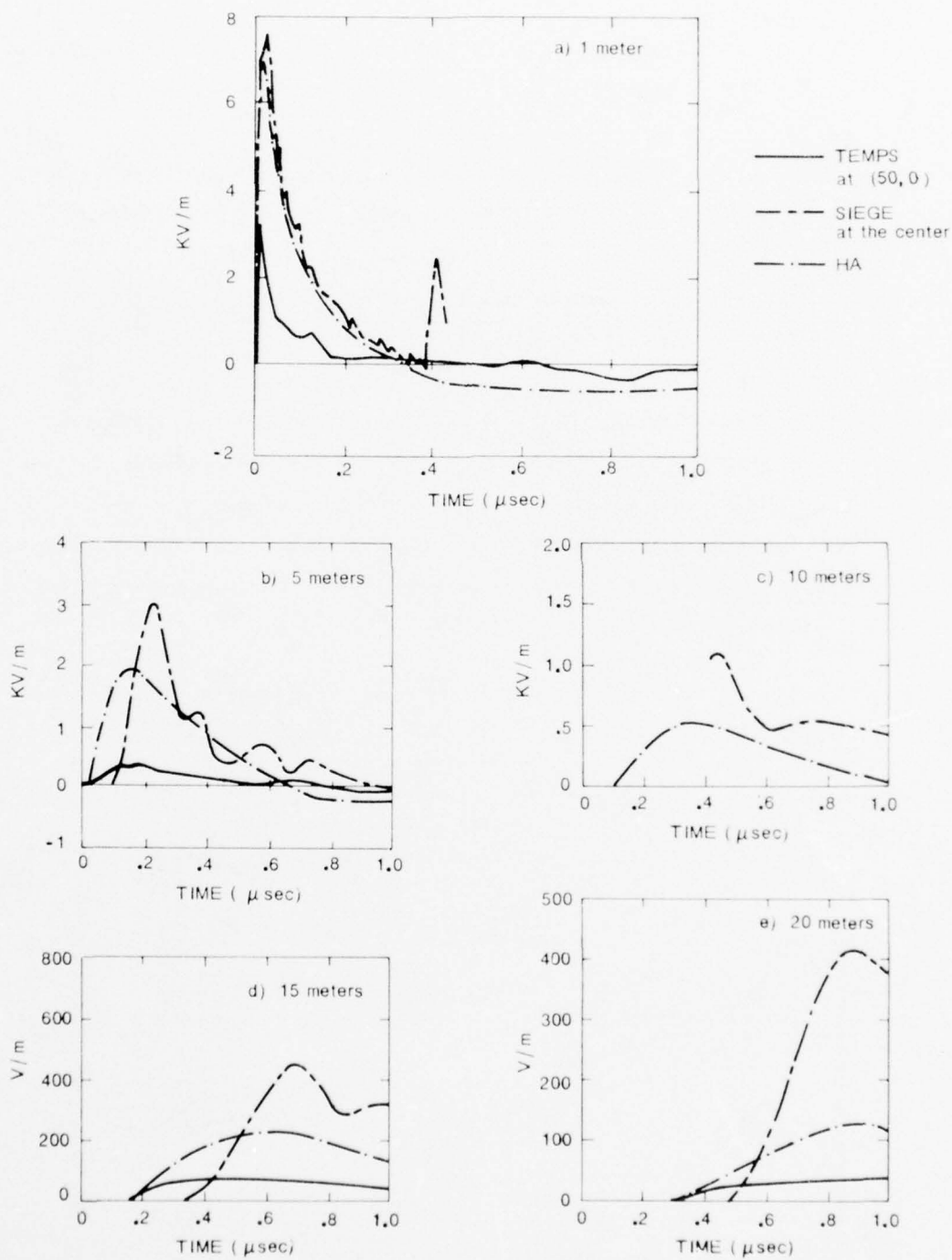


Figure 4-29. Comparison of Underground Electric Field Waveshape for TEMPS, HA and SIEGE

Figure 4-29 compares the waveshape as a function of depth for the three excitations: HA Case 1, TEMPS at  $y = 50$  and  $z = 0$ , and SIEGE at midplane.

It is clear that the risetimes and general waveshapes compare quite favorably for these excitations. The main difference appears to be in the amplitudes.

The currents induced on a buried cable for HA and TEMPS excitation are overlaid in Figure 4-30. It is clear that the differences between them are principally in amplitude. The amplitude difference is because of the reduced value of the TEMPS underground fields and its spatial amplitude variation and phase delay. The exciting voltage sources for the HA are uniform and in phase along the line. The current risetimes appear to be comparable.

The currents induced in an overhead cable by HA and TEMPS excitation are shown in Figure 4-31. Here the amplitudes and waveshapes compare favorably, but differ in detail.

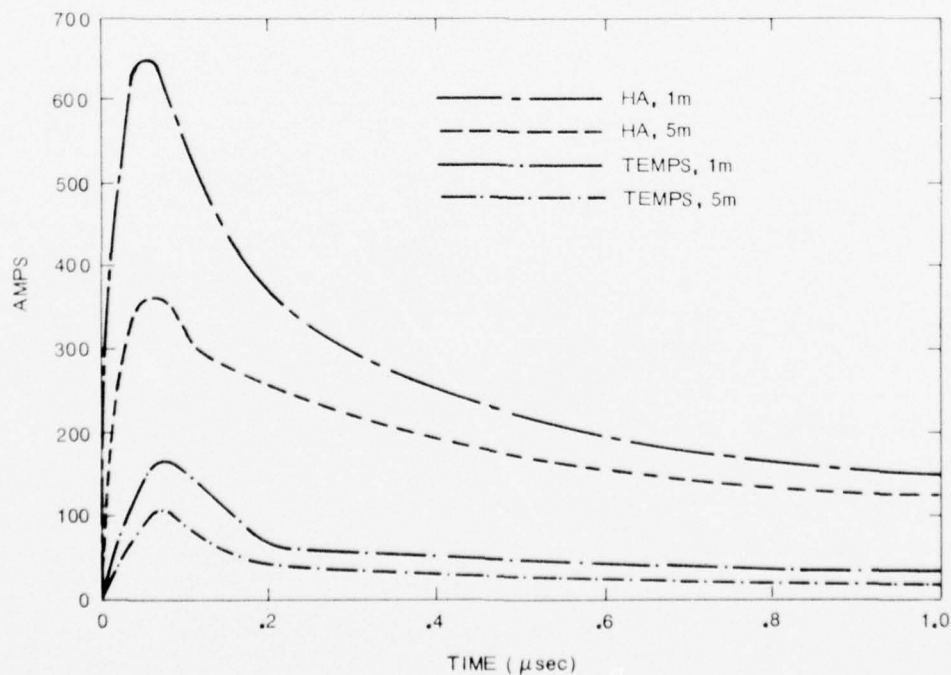
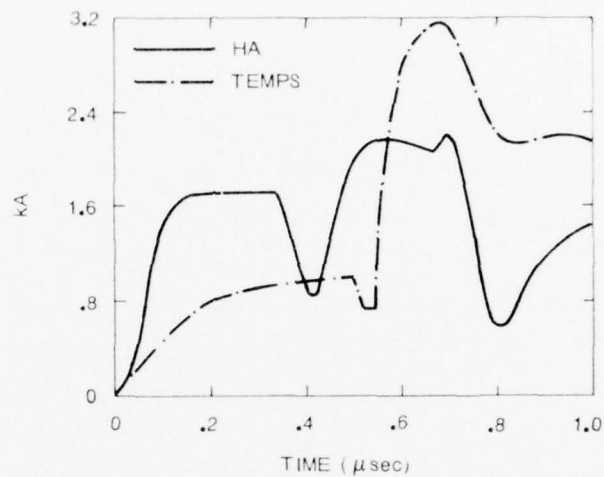
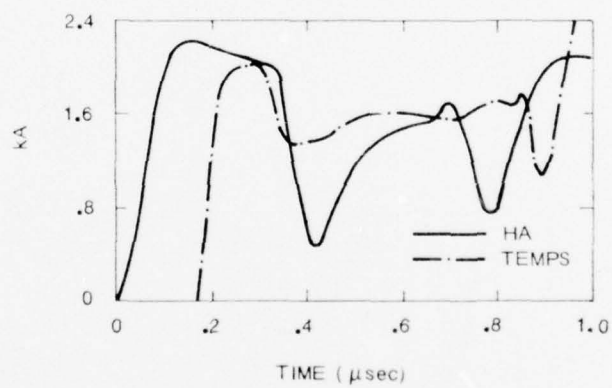


Figure 4-30. Comparison of Buried Cable Currents Induced by HA and TEMPS for a 50 Meter Long Cable



a) CURRENT ON LEFT END



b) CURRENT ON RIGHT END

Figure 4-31. Comparison of Currents on an Elevated Cable for TEMPS and HA Excitation

#### 4.6.6 Currents on an 80 Meter Tall Vertical Tower

In this section, the currents induced on an 80m vertical tower by HA and TEMPS will be estimated. The tower has an average radius  $a$  of 7 meters and a fatness factor  $\Omega = 2 \ln(2h/a) = 6.26$ .

The tower is excited by the incident vertical electric field. For Case 1, the vertical field is 9.5 kV/m, and for Case 2 the vertical field is 15 kV/m. Therefore, calculations will be done for Case 2. Scaling to Case 1 is linear.

The tower currents are estimated by use of Figure 4-32 from Reference 8, which shows the unit step response. For an  $\Omega$  of 6.26, the value is 4.7 ma/m for one volt per meter input. This then yields a current for 5640 amps at the base of the tower.

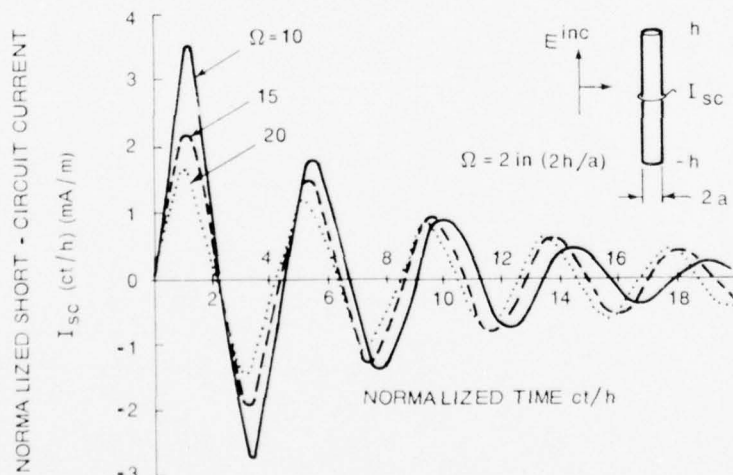


Figure 4-32. Normalized Short-Circuit Current on a Dipole Antenna Excited by a Unit-Step Electric Field Transient

Estimate of current for TEMPS excitation is more difficult. If the tower is located anywhere along the y axis (Figure 4-19), no vertical field is incident on the tower. Estimates will be made for the currents when the tower is located at  $y = z = 50$  meters (Figure 4-19).

The vertical electric field  $E_x$  incident on the tower is given by

$$E_x = E_t \cos \beta \sin \phi \quad (14)$$

where equations (7), (8), and (9) define the quantities used.

For the present geometry, the incident vertical electric field on the tower is an odd function for 20 meters each side of the plane  $x = 0$ . Thus, a first order approximation is that the tower current mainly comes from the top 40 meters. The average vertical electric field in this region is assumed to be the average of the fields at  $x = 20$  and  $x = 60$ , and the result is 13.4 kV/m. This is applied to 40 meters of the tower, and the resultant current estimate is thus 2520 amps. This is approximately one-half of the value obtained from HA.

This approximate answer is based on the following approximations:

1. The incident vertical electric fields varies linearly along the tower.
2. The contributions caused by the incident field along the first 40m of the tower (measured from the ground) is zero.
3. The average field applied to the top 40m of the antenna is 13.4 kV/m. This is not exactly true.

#### 4.6.7 Conclusions

Results have been presented on the underground fields and currents on cables for threat and simulator environments. In this section, conclusions are made regarding the effectiveness of the simulators in reproducing the HA EMP environments and responses.

Several conclusions can be made regarding the reproduction of underground fields:

1. TEMPS has a rather severe (23 dB) horizontal variation of fields over a 100m x 100m quadrant test volume. For a building requiring a quadrant of only 50m, the variation is 18 dB. Thus, it appears that in considering a TEMPS simulation, one needs to determine if this nonuniformity is acceptable.
2. TEMPS risetimes and waveshapes of underground fields compares favorably with those of the HA (Figure 4-29) and the amplitude fall off with depth is very nearly the same (within 1-2 dB).
3. Another difference between TEMPS and HA is that the relative arrival times of the signals on an underground test object is not the same. The difference becomes less severe with increasing depth because of the very long rise-times.
4. The spatial variation of the TEMPS fields is not as severe (less than 6 dB) along the z axis as it is along the y axis (27 dB), as indicated in Figure 4-28. This information may be used to advantage if the test object is rectangular.
5. A SIEGE array requires a larger pulser than does the TEMPS (by a factor of 25) to obtain similar field levels, but the SIEGE array has much better horizontal uniformity of fields than does the TEMPS.
6. The SIEGE underground fields attenuate differently with depth as a function of horizontal position, but only by 5 dB. This is probably acceptable for a given test.
7. The SIEGE fields' risetimes are similar to those of HA.
8. Reflections from the ends of the SIEGE array may pose a problem, and more developmental work would need to be done to determine how severe the problem is and the best way to correct it if needed.

With respect to response of underground cables, several conclusions may be made:

1. The TEMPS-induced currents are smaller than the HA induced currents for the same peak amplitude field incident along the line. This is because of the spatial variation of amplitude and phase of the TEMPS environment.

2. The risetimes of HA and TEMPS-induced currents are very nearly the same.
3. For the soil parameters considered, very little difference in cable response occurred for lengths greater than 50 meters. This is caused by the large lossy propagation constant of the buried cable.

With regard to the response of overhead cable, the following conclusions can be made:

1. Phase differences exist between TEMPS and HA induced cable response because of the nonuniform excitation caused by TEMPS.
2. The amplitudes of the response are within 50% of each other for the case considered.
3. The risetimes of the response are very nearly the same.
4. The waveshapes differ in detail but have a definite similarity (Figure 4-29).

The calculation of the tower currents was a crude estimate based on handbook information. For the tower considered, the HA response was about twice that caused by TEMPS. Differences in arrival times of the fields incident on the tower would affect the waveshape, and a more exact computation would be required to determine the significance of this.

In general, it appears that both SIEGE and TEMPS arrays can be used to simulate HA excitation within certain limits as discussed above. The main limitations are caused by nonuniform simulator fields, and the relative phasing of the induced responses. The exact error in a given simulation would depend upon the types and importance of POEs which exist at the site. The importance of synergistic effects would have to be taken into account because of the relative phasing problem of the various responses. It should also be noted that the SIEGE array is a bounded wave simulator and therefore cannot be used to excite the external penetrators. These would have to be excited separately by a direct drive technique.

## SECTION 5

### TECHNIQUE EVALUATION

#### INTRODUCTION

In this Section, we shall evaluate the various techniques that have been selected for application in a hypothetical, analytical, and experimental assessment of an actual site representative of each of the four classes of sites. For each actual site, a group of proposed techniques will be examined and evaluated and ranked according to the evaluation criteria contained in Section 1.3 and finally, for each site, the various techniques will be ranked according to the findings of the evaluation process.

#### 5.1 SITE 1

Site 1 is characterized as a large complex site with many buildings: some buried, some shielded, some both, some neither. The site is interconnected with many buried shielded cables. The main buildings are designed with EMP protection incorporated. The buildings include electromagnetic shielding, EMP vaults, shielded doors, hardened penetrations, etc. In general, there are many antennas of several types including HF, VLF, microwave and HF satellite uplinks and downlinks. The site is large in extension, up to 1 kilometer square. The generic model of this class of site is shown in Figure 2-1. An actual site representative of this class is shown in plan view in Figure 2-5. For the purposes of this evaluation, the main buried building is the one being subjected to a hypothetical EMP assessment. The other buildings, either buried or on the surface can be considered members of one of the other three classes or as part of the coupling source for the main building POEs. The key features of the main building are: it is buried, electromagnetically shielded, has hardened penetrations (all penetrations enter a single EMP vault). Penetrations are treated with electrical surge arrestors and filters. The penetrations are extensive in area, are in general both buried and above ground. They include power, communication, and antenna cables.

The test techniques selected for application on Site 1 include:

1. Technique 1: Analysis, scale modeling, subsystem (black box) testing.
2. Technique 2: Analysis, CW radiation, POE direct drive (P).
3. Technique 3: Analysis, high level pulse radiation, POE direct drive.
4. Technique 4: Analysis, POE direct drive (P).
5. Technique 5: Analysis, CW radiation, subsystem (black box) testing.
6. Technique 6: Analysis, high level pulse radiation.

#### 5.1.1 Site 1 - Technique 1

In this paragraph, we will proceed to evaluate the applicability and effectiveness of Technique 1 in a hypothetical assessment of actual Site 1.

##### 5.1.1.1 Accuracy of Data

5.1.1.1.1 Analysis. The past history of pretest predictions for the magnitude of currents and voltages coupled to buried POE cables is accurate to within  $\pm 9$  dB standard deviation ( $\sigma$ ). The accuracy with which the electric and magnetic field can be predicted as a function of depth and soil parameters ( $\sigma, \epsilon, \mu$ ) is known to within  $\pm 5$  dB standard deviation. (See reference 1.)

Assuming that the buried building shielding is well designed from a RFI point of view, is designed to stand up throughout its projected lifetime (i.e., not subject to settling, cracking, corrosion, gasket abuse, etc.), tested during construction to verify that the shielding meets design specifications, and is not violated in unforeseen manner, then the field inside the building can be predicted for a given external field outside to within 1 or 2 dB of the accuracy of the original test data (ignoring the effects of internal structure and equipment). Given the above assumptions, it can be stated that coupling of fields inside the building to interior conductors within the building is negligible. Hence, the voltage and current seen at each of the critical interfaces can be predicted based upon propagation from the point of entry to the interface. From past EMP assessment predictions and subsequent testing, interface voltage and current can be predicted with an accuracy of  $\pm 22$  dB.

Given the interface voltage and current, it is necessary to know the damage and upset threshold of the critical equipment at the critical interfaces. The value of these thresholds can be predicted analytically by use of existing SUPERSAP style data base, or by simple analyses of the interface components. Typical accuracies for threshold analyses are  $\pm 5$  dB.

Combining these sources of error we arrive at a total uncertainty in the analytic assessment of approximately  $\pm 25$  dB for one standard deviation.

5.1.1.1.2 Scale Modeling. The HDL scale model facility at Woodbridge, Virginia is currently measuring voltage and current to within  $\pm 6$  dB, compared to theoretical prediction. It is felt that with a modicum of effort, the measurement error could be reduced to less than  $\pm 3$  dB.

A problem of particular interest in scale modeling Site 1 to measure scaled POE currents is the difficulty in scaling the effects of the soil in which the buried cables are submerged. However, it is felt that given actual measured parameters of the soil to be used at the site that these parameters can be modeled to within 2 dB in the laboratory. Extrapolation of the scaled fields to threat involves data processing errors of  $\pm 2$  dB.

Given that the error bounds for all the components add in quadrature the total standard deviation for scale modeling testing is

$$\sqrt{3^2 + 2^2 + 2^2} = 4.1 \text{ dB} \approx 4$$

5.1.1.1.3 Subsystem (Black Box) Testing. The purpose of subsystem testing is to determine the failure and upset levels of the interfaces for critical equipment. The measurement techniques used in black box testing are normally accurate to within  $\pm 1$  dB. However, the statistical variation of damage thresholds within a given class of components can vary considerably. For typical classes of discrete, solid state components, the statistical variation of damage thresholds can be  $\pm 3.5$  dB. Moreover, black box testing at the subsystem

level obviates the need to model the coupling path from the subsystem level to the circuit level. This results in a total of 5 dB improvement in the assessment accuracy.

5.1.1.1.4 Overall Technique Accuracy. In Section 3, we pointed out that there are seven essential elements of an EMP vulnerability assessment. Each of the key elements can be determined analytically and/or experimentally. We have assumed for the purposes of this evaluation that all would be determined analytically using techniques with known accuracies similar to that used in the PREMPT Program. Hence, the applicability of the test techniques lies in their ability to increase the confidence (decrease the error bound) of the analysis in each of the seven areas. For purpose of this evaluation, it is assumed that there is zero error in the determination of the coupling of fields to internal conductors because of the shielding characteristics of the building. We also assume zero error in assessing the shielding effectiveness of the building, although this assumption may vary with time. The two test techniques that we have evaluated increased the confidence in the area of: (1) decreasing errors in coupling of voltages and currents to POEs from 1 to 2 dB based on scale model testing, and (2) reducing errors in upset and damage thresholds at the subsystem level from black box testing by 2 dB. However, Technique 1 does not address propagation of the POE coupled signals in the interior of the structure. Hence, the overall error of the predictions generated using Technique 1 would be improved by 7 from approximately 25 dB to 18 dB, *one standard deviation*.

#### 5.1.1.2 Site 1 - Technique 1 - Cost Factors

In this Section we will evaluate the relative costs of each of the methods used in Technique 1. This is a relative costing only based upon current engineering judgement. It must be borne in mind that EG&G is not attempting to tell the Government or any of its contractors what an actual assessment of an actual site of this type should or would cost. The intent here is merely to make crude order-of-magnitude estimates so that the various techniques can be ranked according to relative expense versus relative return.

5.1.1.2.1 Analysis Costs. The costs of performing an analysis and pretest prediction on a complex site can be crudely bracketed by assuming a detailed PREMPT style assessment as the upper bound and an abbreviated assessment as a lower bound. However, since at this time, the details in the complexity of the site are not known, these are simple order-of-magnitude costings. The approach to costing this type of effort has been to assume that an average engineering manhour costs of \$25.00, and an average technician or data clerk or technical aid costs of \$15.00 per manhour. The approximate resource requirements for a detailed assessment are shown in Table 5-1.

Table 5-1  
Site 1 Detailed Assessment Labor Requirements

<u>Task</u>	<u>Labor Requirement</u>	<u>Manhours</u>
Site Survey	4 Engineers 2 weeks	320 engineering hours
Modeling	4 Engineers 12 weeks 2 Aid/Clerks 12 weeks	1920 engineering hours 960 tech hours
Software Support	1 Programmer 10 weeks	400 engineering hours
	TOTALS	2640 engineering hours 960 tech hours
	2640 x \$25	\$66,000
	960 x \$15	<u>14,400</u>
	Total	\$80,400
	Travel	6,000
	Computer Time	<u>10,000</u>
	TOTAL	\$96,400

Resource requirements and costs for an abbreviated assessment are shown in Table 5-2.

Table 5-2  
Site 1 Abbreviated Assessment Labor Requirements

<u>Task</u>	<u>Labor Requirement</u>	<u>Manhours</u>
Site Survey	2 Engineers 2 weeks	320 engineering hours
Modeling	2 Engineers 4 weeks	320 engineering hours
Software Support	N/A	
	TOTAL	640 engineering hours
	640 x \$25	\$16,000
	Travel	6,000
	Computer Time	<u>2,000</u>
	TOTAL	\$24,000

The \$25.00 per engineering manhour, and \$15.00 per technician manhour are used regardless of whether the test is long term, short term, on-site, or off-site. This is assumed because short term tests even though off-site usually use fully loaded costing because home site facilities will be required when the personnel return. Long term, off-site testing is sometimes priced with separate off-site reduced overhead but the additional cost of travel has to be considered.

5.1.1.2.2 Scale Modeling. For purposes of pricing a typical scale model test, we have assumed that a GFE scale model facility will be provided and that this facility will include environment generators, probes, sensors, instrumentation and all supporting hardware. Thus, the scale model price includes design of the model, fabrication of the model, actual testing and reporting. The cost resources required are shown in Table 5-3.

5.1.1.2.3 Subsystem (Black Box) Testing. For purposes of pricing typical black box threshold testing we have assumed a subsystem test facility will be provided as GFE. This facility will include drivers, sensors, probes, instrumentation, and all supporting hardware. For the purpose of this paragraph, we have assumed that the Air Force Weapons Laboratory Programmable Universal Direct Drive (PUDD) or equivalent would be provided.

Table 5-3  
Scale Model Test Costs

<u>Task</u>	<u>Manhours</u>
Design Model	320 engineering hours 160 tech hours
Fabricate Model	160 engineering hours 320 tech hours
Test	320 engineering hours 320 tech hours
Reporting	80 engineering hours
TOTAL	880 engineering hours 800 tech hours
880 x \$25	\$22,000
800 x \$15	<u>12,000</u>
	\$34,000
Material	500
Shipping	1,000
Travel	<u>8,000</u>
TOTAL	\$43,500

From past EG&G experience in operating the PUDD, it has been found that a typical black box test requires 193 engineering manhours and 99 technician manhours. Thus, the total cost of an average, typical black box test in a GFE facility is \$6,310. This does not provide any of the circuit analysis or functional analysis. Since "Analysis" is a part of the technique, these functions are assumed to be performed there. This paragraph covers cost of test only. This is consistent with methods currently completed in the assessment of aircraft subsystems. For a large complex system such as Site 1, a minimum subsystem test program should include 10 "black boxes." Thus, an approximate cost of \$65,000 can be expected.

If a test facility is not made available, the cost of a test is increased by the cost of building or renting a test facility. This could cause the cost of the test to increase by at least a factor of two and up to a factor of 5 depending on complexity and amortization of new test facilities.

5.1.1.2.4 Cost - Technique 1. By simple addition of all of the above components, it can be seen that the cost of a site assessment using Technique 1 would fall between the limits of \$132,500 and \$204,000.

#### 5.1.1.3 Duration of Test

In evaluating the duration of both the hypothetical scale model test and hypothetical black box direct drive test, it has been assumed that in both cases the test facility would be GFE and that it would be readily available and that only minimum modifications to the facility hardware would be required so that no undue delays would be incurred.

5.1.1.3.1 Scale Model. The various phases of a scale model test are: (1) design model, (2) build model, (3) prepare test plan, (4) test, and (5) reporting. For the simplified scale model test envisioned for Site 1, each phase would take approximately one month. Hence the total duration of the test would be five months.

5.1.1.3.2 Subsystem Test. Past experience using the PUDD at Kirtland AFB has shown that it takes approximately one month for a complete test cycle of a black box. If we assume that this facility assessment would require testing of ten black boxes, the total test duration would be approximately ten months. Note that the one month's duration is for a "typical" average complexity black box. Should all six of the boxes be extremely complex in function and test requirements, the duration of the test could exceed ten months.

#### 5.1.1.4 Practicality

Technique 1 would be an extremely practical and simple technique to implement for either of the proposed test programs. Very few agencies would be involved. They are: (1) the sponsoring agency, (2) test facility owner, (3) the testing agency, and (4) the owner or SPO for the black boxes

to be tested. In both cases the facilities are reasonably small and simple. They are currently in existence and normally available for relatively small, simple tests such as the ones proposed.

#### 5.1.1.5 Interference with Facility

None of the testing proposed in Technique 1 takes place at the actual site, therefore, the interference at the facility would be zero.

#### 5.1.2 Site 1 - Technique 2

Technique 2 consists of Analysis, CW Radiation, and POE Direct Drive (pulse). This technique has been selected for use on Site 1 primarily because of the effective shielding and hardening of the penetrations at Site 1. Because Site 1 is both buried and shielded, there is no adequate simulation technique to increase the analytical confidence in the environment at the depth of the site or for the coupling to the points of entry. In addition to this, because of the effective shielding, coupling of internal fields to the conductors inside the site is not a factor. Hence, the only areas that simulation can increase the confidence over and above that of the analysis, is in verifying the effectiveness of the protection devices on the points of entry, verifying the shielding effectiveness, and verifying the propagation from the penetration to the critical interfaces, and in narrowing the error bound on the determination of upset and damage thresholds at the critical interfaces. Thus, the combination of methods used in this technique, addresses almost all areas in which simulation can be used to increase the confidence of the assessment. The sole missing element is black box testing to minimize errors in threshold predictions.

#### 5.1.2.1 Data Accuracy

5.1.2.1.1 Analysis. The analysis approach to be used in Technique 2 is identical to that used in Technique 1. Hence from Paragraph 5.1.1.1 the one sigma error bound associated with the analytical assessment for this type of site is 25 dB.

5.1.2.1.2 CW Radiation. There are two types of radiated CW attenuation measurement experiments. One technique commonly used in EMP experiments is to radiate the site using a swept CW source such as a Hewlett Packard sweep

generator, a high power amplifier and a monopole radiating antenna. Because CW signals of much lower amplitude can be measured using tuned receivers, this technique allows direct measurement of the transfer function from the field to a critical interface in the frequency domain. Another technique more commonly associated with EMI/EMC is to drive from inside of the shielded enclosure a variety of antennas at different frequencies and measuring the attenuation of the field with receivers on the outside of the enclosure. For a site such as Site 1 which has been designed to have high attenuation over the bandwidth of interest and whose penetrating cables are primarily buried, the use of the monopole radiator would probably not generate usable signals inside. Inasmuch as the basic objective of a CW radiated test of a site like this is to verify the shielding integrity, or to look for RF leaks or inadvertent penetrations; and to verify that the building meets design specifications, the second EMI/EMC type CW test is recommended. It is well known that the type of equipment used in this type of testing can achieve accuracies of  $\pm 2$  dB. Additional errors associated with transforming the data to the time domain and extrapolating to threat might add an additional 1 dB because of the absence of phase data. Hence the overall accuracy of the CW radiated measurement could be between 2 and 3 dB. However, since a reasonable design goal for such a buried shielded building is 120 dB, these accuracies are acceptable in that they would verify design specifications to within a few dB and thus eliminate completely from the assessment problem coupling of fields to internal conductors.

A more common practice in EMP assessment and test programs is to radiate a site with CW radiation from a monopole antenna. Either discrete frequencies are used to spot check or a swept frequency generator is used. Use of a swept CW generator allows the direct measurement of a transfer function from the field to measurement point of interest. Because Site 1 is well shielded, let us examine in an order-of-magnitude way, the sorts of signals to be expected.

In order to illuminate the site with plane wave, arbitrarily defined as one whose nonprinciple components are less than 10 percent of the principle, we can arrive at a distance R which should separate the monopole from the test site. See Figure 5-1.

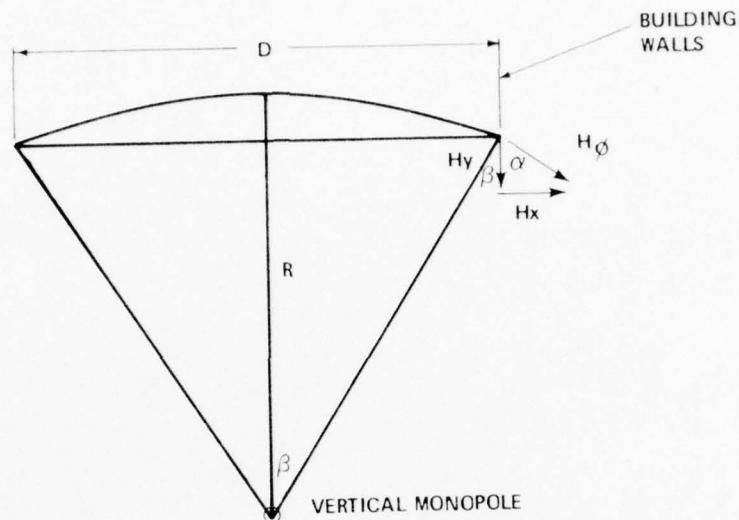


Figure 5-1. Illuminating a Building with a Vertical Monopole

Definitions:

1. acceptable planarity:  $H_x \geq 10 H_y$
2.  $D$  = dimension of test object
3.  $\beta = 90^\circ - \alpha$

From 1)  $H_x \geq 10 H_y$

$$\frac{H_x}{H_y} = \tan \alpha \geq 10$$

$$\alpha \geq \arctan 10 = 8.43^\circ$$

$$\beta = 90 - \alpha \geq 81.57^\circ$$

$$\tan \beta = \frac{D/2}{R} \leq .099 \approx .1$$

$$R \geq 10 D/2$$

For Site 1

$$D = 104\text{m} \quad D/2 = 52$$

$$\therefore R \geq 520\text{m}$$

For an isotropic radiator,

$$P = \frac{P_t}{4 \pi R^2}$$

For a vertical monopole

$$P \approx \frac{3 P_t}{4 \pi R^2}$$

where P is the Poynting vector

For a transmitter radiating 10 watts of power at 520 meters

$$P = \frac{30}{4 \pi (520)^2} = \frac{30}{3.4 \times 10^6} = 8.8 \times 10^{-6} \text{ watt/m}^2$$

$$P = \frac{E^2}{377}$$

$$E^2 = P \times 377 = 8.8 \times 377 \times 10^{-6}$$

$$= 3.3 \times 10^{-3}$$

$$E = 5.7 \times 10^{-2} \text{ v/m}$$

$$B = \mu H = \mu \frac{E}{377} = 1.8 \times 10^{-10} \text{ tesla}$$

Assume an 80 dB building shield (a modest assumption)\*

$$E \text{ inside} = 5.7 \times 10^{-6} \text{ v/m}$$

$$B \text{ inside} = \mu \frac{E}{377} = 1.8 \times 10^{-14} \text{ tesla}$$

for

$$\omega = 2 \pi \times 10^7 \text{ (f = 10 MHz)}$$

$$\dot{B} = 1.1 \times 10^{-6} \text{ tesla/sec}$$

Using the largest, most sensitive  $EC^{\circ}G$  magnetic field sensor, the MGL-1, which has an equivalent area ( $A_{eq}$ ) of  $10^{-1}$  square meters,

$$V = A_{eq} \dot{B}$$

$$V = 10^{-1} \times 1.1 \times 10^{-6}$$

$$V = 1.1 \times 10^{-7} \text{ volts}$$

\*The fields inside are not related by  $E = 377H$ , nor are they uniform in space. We make this assumption here only for the sake of simplicity. Since the 80 dB applies to the least attenuated field component.

Add -20 dB earth attenuation (also a conservative assumption at 10 MHz)

$$V = 1.1 \times 10^{-8} \text{ volts}$$

Since all assumptions are conservative and most frequencies are attenuated more than 1 MHz, we see that measuring the magnetic field inside the building is impractical. One might consider using a more powerful transmitter or moving the antenna closer. However, even a 1 kilowatt transmitter improves the signal only one order of magnitude which is still too small to measure accurately. Moving the transmitter closer to the site degrades the planarity of the wave and requires that additional analysis be performed to derive the transfer function.

In an experiment at HDL Woodbridge (WRF) in 1973, see Reference 3, EG&G excited five buried conduits and measured the current on wire inside and shorted to the conduit at the end. The conduits were buried six feet (1.83m) and were 99 feet (30.195m) long. They were excited by an overhead array as shown in Figure 5-2. Each of the conduits was flawed and the objective was to locate the flaws. The measured array current was 0.88 amps.

The array width was 8 feet (2.44 m) which gives an effective surface current density.

$$\begin{aligned}\sigma &= .88/2.44\text{m} \\ &= 0.36 \text{ amp/meter}\end{aligned}$$

For radiated case:

$$\hat{n} \times \vec{H} = \sigma$$

Assume

$$\vec{H} \perp \hat{n}$$

then

$$\sigma = H = \frac{E}{377}$$

at 520m

$$\sigma = 1.5 \times 10^{-4} \text{ amp/meter}$$

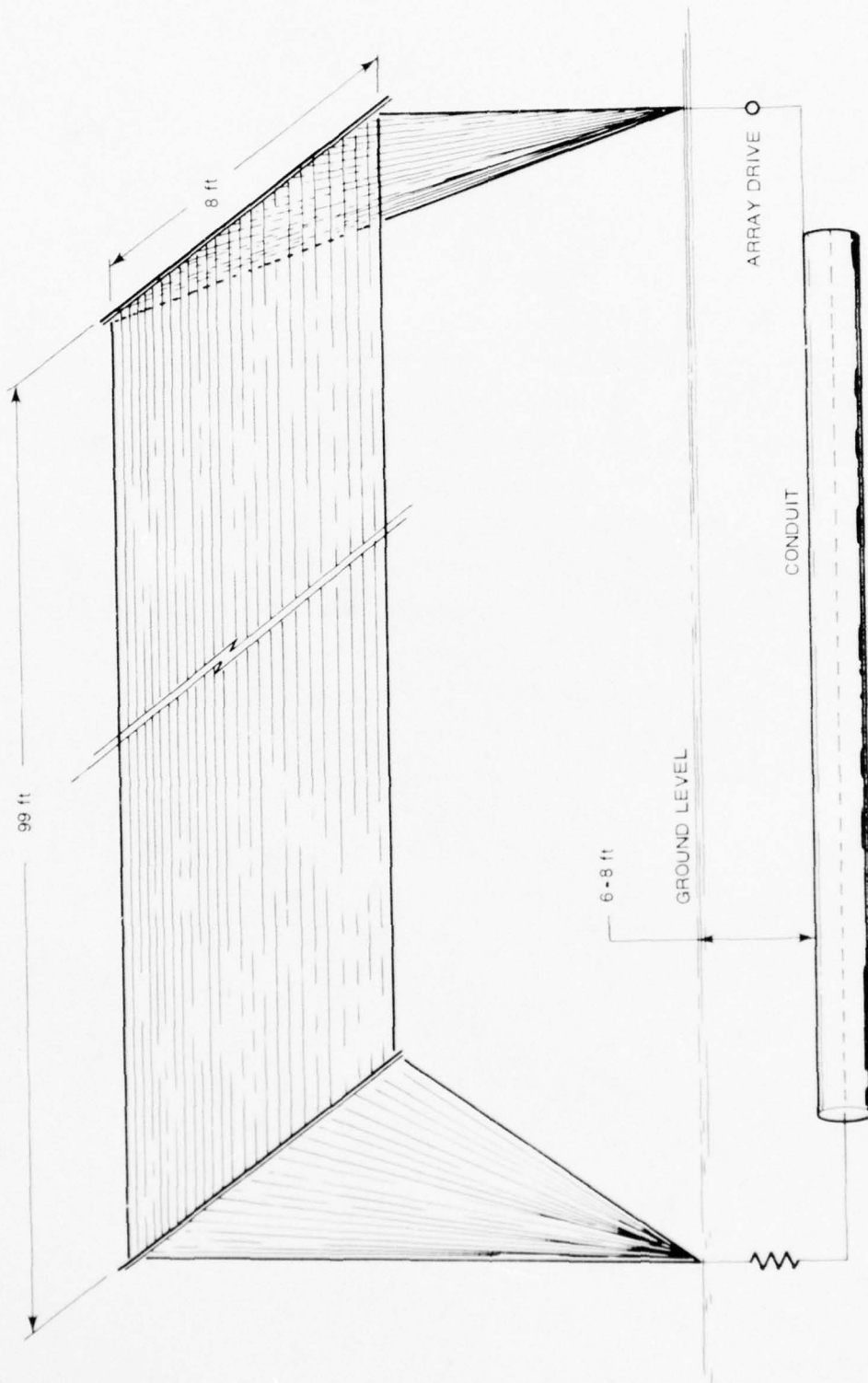


Figure 5-2. Buried Conduit Excited by Overhead Array

Thus, the surface currents excited in the vicinity of Site 1 are 60 dB less than in the WRF experiment.

Inasmuch as the signals in some of the flawed conduits were too small to record accurately, and the signals predicted for cables inside Site 1 conduits are much smaller (even with a 1 kilowatt transmitter), use of this technique is not recommended for Site 1.

5.1.2.1.3 POE Direct Drive (Pulse). The instrumentation used to record the data during the Phase I and Phase II cable driving tests at the Delta, Utah PREMPT Site was analyzed to have an accuracy of  $\pm 2$  dB based upon the known accuracy of each of the components. An analysis of the repeatability of the cable drive data indicated a maximum spread at repeat test points of 3.1 dB. A weighted average spread would then be approximately 1-1/2 dB, roughly equal to the given accuracy of the measurement system. If we assume the two to be statistically independent, and add them in quadrature, then the error bound on the data is 2.5 dB. This is a conservative estimate because they are probably not statistically independent (Reference 4).

Inasmuch as the models developed for the pretest predictions can utilize as an input the output of the direct drive pulser, there is no additional error involved in scaling to threat if required. Hence, the overall error in the direct drive experiment is approximately 2.5 dB.

5.1.2.1.4 Overall Accuracy, Technique 2. Starting with a baseline of 25 dB analysis quality, the test techniques increase the assessment confidence as follows.

The results of CW testing are difficult to quantify. The test is intended to verify the shielding integrity of the site. In this sense, it is a go-no-go type test. There is no statistical data available to show what the standard deviation building construction from shielding design goal.

The POE Direct Drive (Pulse) test reduces errors in coupling from POE to circuit and in threshold predictions. If adequate threat level POE pulse drive is used, the error in transfer function from POE to circuit is reduced from 13 dB (see Figure 3-1 a) to 2.5 dB. The net improvement is 10 dB. Thus, the quality of a Technique 2 assessment is 15 dB.

#### 5.1.2.2 Cost Factors

The cost of the analysis portion of Technique 2 is the same as Technique 1.

5.1.2.2.1 CW Radiation. Without having detailed information on the external and internal structure of Site 1, it is difficult to accurately predict the cost of determining the attenuation of the structure experimentally. However, with the use of some reasonable simplifying assumptions and a good deal of engineering judgement based on past experience, it should be possible to come up with a relative approximate cost. The assumptions used in this evaluation are:

1. RF drive from inside, measure from outside
2. Measure only from 10 kHz, 100 MHz, i.e., the bandwidth of interest for EMP
3. Assume the building is shaped like a rectangular parallel-piped that is each side a rectangle but not necessarily square
4. Assume a drive point:
  - At or near the center of each of the six sides
  - At or near each of the eight corners
  - At or near the center of each of the 12 edges
  - At or near the center of each of the four quadrants
5. Measure at four points roughly equivalent to the four corners of the top surface at the surface of the earth above the building.

Thus, there would be 120 combinations of drive and measurement. From past EMI/EMC experiments, it is reasonable to expect that two men could complete two complete measurements per day. This is a conservatively slow estimate based upon the probability of difficulty in communication. In addition, it will require approximately one man four weeks to organize, analyze, and report the data. Thus, 140 mandays or 1120 engineering manhours would be required for this test. At the assumed rate of \$25.00 per hour, the cost of such a test would be approximately \$28,000.

5.1.2.2.3 POE Direct Drive (Pulse). At the Polk City Autovon Site, a very extensive and complete cable drive program was performed. The cable drive program took approximately three months and required the following personnel:

- 10 Technicians
- 1 Cable Drive Technician
- 1 Data Clerk
- 3 Engineers
- 1 TEMPS Team Manager

Inasmuch as the Team Leader or Manager's presence was required primarily because of the TEMPS testing, he will not be considered in costing and the equivalent POE direct drive experiment which could be performed with only the three engineers. Thus there were a total of 5,760 technician hours at a cost of \$86,400 and 1,440 engineering hours at a cost of \$36,000. Hence, the total labor cost was \$122,400. It is estimated that additional material and supplies and shipping costs were \$10,000 for a total field program cost of \$132,000. This was a very large complex facility with many untreated POEs. For a facility with controlled, hardened POEs, a test of approximately half this magnitude should suffice. However, it is reasonable to assume that a program at a site such as Site 2 would cost between \$65,000 and \$135,000.

5.1.2.2.4 Cost Technique 2. An assessment of Site 1 using Technique 2 would cost between \$105,000 and \$355,000.

5.1.2.3 Duration of Test

Both tests could be run concurrently with little or no interference. It is perhaps even desirable, that the CW testing be performed during construction so that any inadvertent leaks could be corrected. An additional advantage of testing during the construction phase is that testing measurements of attenuation of the shielding alone without the overburden could be performed if desired. Should the direct drive of the POEs be as comprehensive as that performed at Polk City, a total test duration of three months could be encountered and additional four to six weeks of equipment setup and takedown. Thus, a test program of from ten weeks to four months could occur.

#### 5.1.2.4 Practicality

This would be an extremely practical technique to implement in that a limited number of agencies are required, all of the hardware that is required currently exists and several government agencies and/or civilian contractors have the required expertise to perform the tests and integrate the results. The CW radiation would require one contractor or government agency. The direct drive program would require one agency or contractor plus the GFE pulsers from the HDL, AFWL, or SAMSO pulser inventories plus data acquisition instrumentation.

Very little in the way of data reduction and processing time or equipment would be required. Shipping of the equipment and simulators would also be a practical matter since no extremely large or bulky simulators or instrumentation would be required.

#### 5.1.2.5 Interference with Site

The CW shielding test should be performed during the construction phase or before the site is backfilled and buried. A delay in the construction of up to three in the construction could be incurred. During the POE tests, site operation, if started, could continue. Assistance from site personnel would be required to locate and access test points. In a high level POE test, as in any high level test, a possibility of upset or damage exists.

#### 5.1.3 Site 1 - Technique 3

Technique 3 consists of analysis, high level pulse radiation, and POE Direct Drive (P). Technique 3 differs from 2 in that high level pulse is used rather than CW radiation. This overcomes the shortcoming of the CW approach, which is that system elements are not driven to threat or nonlinear levels. In the case of a well-shielded building, such as Site 1, high level pulse radiation provides the additional advantage of higher level signals and

increased dynamic range of test. Thus, such a combination as Technique 3 could provide high threat level radiation testing, combined with facility response testing, and high level direct drive testing on all pertinent POEs even though, they are not adequately illuminated by the high level pulse radiation.

5.1.3.1 Accuracy of Data

5.1.3.1.1 Analysis. As indicated in Paragraph 5.1.1.1, an analytic assessment of this type of facility can be completed to within approximately  $\pm 25$  dB standard deviation.

5.1.3.1.2 High Level Pulse Radiation. The usefulness of a high level radiated pulse simulator can be evaluated from two distinct perspectives. Depending on one's point of view there are two separate criteria. They are:

1. The adequacy of the simulator, i.e., field levels at building depth compared to the threat level field levels at the same depth, and currents induced by the simulator at the POEs as compared to currents induced on similar POEs by a threat level pulse, and
2. The useability of the data. That is, will the data taken in the three common types of measurements (internal fields, points-of-entry voltage and current, and interface voltages and currents) be of sufficient magnitude and have sufficient signal-to-noise ratios to allow for reasonable interpretation.

From Section 4.6 we see that the fields induced at the top of the building (5 meters below grade) are approximately 13 dB below HA in the case of TEMPS and over 10 dB above HA in the case of SIEGE. This means that the TEMPS simulator produces smaller fields than threat, but is still in the realm of adequate simulation. On the other hand, the SIEGE type simulator produces simulation which is marginal at best because it does not excite the POEs outside the buried array. Also, from Section 4, we see that current induced on cables by a TEMPS simulator (cables up to 100 meters in length) are approximately 14 dB below threat, whereas the SIEGE simulator by its very nature provides negligible excitation for either buried or overhead cables. Thus, for a large buried facility with extensive numerous POEs, SIEGE can be eliminated as potential threat level simulator for Site 1 because of the inadequacy of POE excitation.

From the above we can see that while SIEGE is not considered an adequate simulator, TEMPS provides small but adequate field illumination and POE excitation. We shall now evaluate the usefulness of the TEMPS simulator in an EMP vulnerability assessment program of a well shielded site, such as Site 1, based upon the second criteria - usability of the data.

Referring once again to Section 4, we see that the TEMPS induced peak electric field at a depth of -5 meters is a  $2.6 \times 10^3$  volts per meter. As before, we assume a conservative 80 dB field attenuation due to building shielding, thus TEMPS induced fields inside the building are of the order of  $2.6 \times 10^{-1}$  volts per meter. At the 5 meter depth, the H field induced by TEMPS is equal to 6.4 and the B field is  $8.6 \times 10^{-6}$ . Hence, the interior magnetic field is  $8.6 \times 10^{-10}$  tesla. The risetime of the external field at this depth is approximately 600 nanoseconds. Assuming an interior risetime of approximately 1 microsecond,  $\dot{B} = 8.6 \times 10^{-10} \div 1 \times 10^{-6} = 8.6 \times 10^{-4}$ , and using the largest equivalent area MGL  $\dot{B}$  Sensor, which has equivalent area of 0.1 meters squared, this gives an output signal of  $8.6 \times 10^{-5}$  volts. This signal is within the dynamic range of present oscilloscope/camera recording systems only if a 40 dB amplifier is used. However, this is the anticipated peak value; details of the time history and frequency content may be difficult to interpret. Moreover, should total magnetic attenuation exceed 80 dB over an appreciable portion of the EMP frequency band, the peak may be too small to measure accurately. Naturally the converse is also true and the signals may be larger. The situation will be further complicated by the installed equipment which enhances and shields field in a nonanalytically predictable manner. From this we conclude that TEMPS is marginal as a tool mapping interior field level.

We shall now proceed to evaluate the applicability and usability of the TEMPS simulator to measure coupling of fields directly to external coupling

paths (penetrations). From Section 4, we see that currents induced upon buried cables at the 5 meter depth for cables both 50 and 100 meters in length, the currents are in the order of 60 to 80 amps. For greater depths these currents are smaller, therefore, this is a best case analysis as far as inducing usable signals in a cable. Assuming a very conservative cable shielding effectiveness of 60 dB, the amount of this total current induced on the interior bundle of conductors would be in the order of 60 to 80 millivolts. This is indeed a measurable signal level using Singer type bulk current probes with transfer functions of 1 ohm. However, this has been such an exceedingly conservative evaluation, ignoring such factors as:

1. The division of the core current among many conductors,
2. The additional 40 to 60 dB attenuation encountered in propagation from the point of penetration to the critical interface,
3. The fact that most signal cables have considerably more than 60 dB shielding effectiveness, and
4. The buried cables will, in all probability, be buried at depths greater than 5 meters.

We can reasonably conclude that although there is a high probability of useful data being taken on some interface circuit measurements, there is a very small probability of being able to adequately map the distribution of currents throughout the facility and determining the transfer functions from fields to critical points with any reasonable degree of accuracy. Hence, we can conclude the TEMPS simulator is not a useful simulator for performing the type of full-scale EMP pulse radiation facility tests such as has been performed in the PREMPT Program.

Having shown that neither the SIEGE nor the TEMPS simulators are adequate tools for performing a "classical" facility EMP test, one can reasonably ask, "Is there any reasonable application for such high level pulse testing?" In the case of a newly constructed building incorporating modern shield design goals, null or zero results and the absence of any facility response, e.g., upset or damage, constitutes meaningful data and can contribute to a

successful test. Thus, a high level radiated pulse test could be successfully performed as a quick and simple verification test of building shielding and building penetration hardening. Should significant field levels be encountered, or should significant current be measured on the inside of the points-of-entry, one could immediately conclude that there was a deficiency either in the building design or a variance in the building construction from building design.

5.1.3.1.3 POE Direct Drive (P). From Paragraph 5.1.2.1.3, we have already shown that the accuracy of measurements in Direct Drive (P) testing is  $\pm 2$  dB, and the overall accuracy of the test technique to be approximately 2.5 dB.

5.1.3.1.4 Overall Technique Accuracy. Given that the error in the prediction of voltages and currents at the penetration of the point-of-entry is 9 dB and that the error of the prediction at the circuit level is 22 dB and that they add linearly, the improvement in the prediction realized by the *Direct Drive* point-of-entry test is 10 dB (from 13 to 2.5 per Figure 3.1 a). The accuracy of the assessment as refined by the results of this test would then be 15 dB, or 10 dB improved over that based on visual site survey alone. The accuracy of the Site 1 predictions would not be affected by a TEMPS test because the data taken during such a test would predominately null the data, (assuming a "classical" assessment type TEMPS test program).

5.1.3.1.5 Modification to the TEMPS Pulser or Antenna. Given that we have concluded that the TEMPS simulator is not a useful tool for testing a facility such as Site 1, one can logically ask, "Are there simple modifications to the TEMPS pulser or antenna which would make it a useful tool?" The TEMPS coverage area and the peak-free field, electric field values are shown in Figure 4-10. For a test object to be illuminated by the early fast rising peak field, with  $< 10$  percent field nonuniformity, that test object must be within a  $26^\circ$  angle from the center line shown in the illustration. By observation, the 104 meter by 90 meter buried buried building would have to be located at the 100 meter distance on the center line. At this distance, the peak-free field is already reduced to 26 kV per meter which would mean that data which is already too low to be useful in an assessment program would be reduced by an additional factor of 2.

Lengthening the Late Time Radiating Antenna would not significantly affect the peak value of the free electric field at this range because this is governed primarily by the early time radiation from the bicone. Within the 26° TEMPS coverage angle, only the late time fields are supported by radiation from currents in the late time antenna. Therefore, changing the length of the antenna would change the logarithmic decrement of the decaying pulse, but would not affect the peak field. Inasmuch as it has already been shown that these fields are marginal to inadequate at the 50 meter point and the 100 meter point, one must conclude that lengthening the antenna would not significantly increase the usability of the TEMPS simulator.

Another potential modification to the TEMPS to increase the efficiency with which energy is coupled into and below the ground, would be a modification of the ground connection at the termination of the late time antenna. One could, by driving a ground system to great depths in the ground, force the TEMPS antenna currents to greater depths. However, it was shown in analysis of the SIEGE type array that the buried transmission line current required for HA level fields at or near the surface far exceeds the capability of the TEMPS pulser. Thus, although a detailed quantitative study of an optimum TEMPS/ground interface has not been performed one can reasonably conclude that it would not decrease test deficiencies to the point where useful data could be produced.

#### 5.1.3.2 Costs

The cost for analytic assessment in Technique 3 is the same as for Techniques 1 and 2.

5.1.3.2.1 High Level Pulse Radiation. The rental cost for a TEMPS simulator amounts to roughly 1 to 1.5 million dollars per year. This fee includes the cost of instrumentation and operating crew. Because of the highly variable expenses involved in site preparation and test preparation, transportation and assembly, exact cost estimates for a test of Site 1 would have to be determined based on test objectives for such a site. Nonetheless for any TEMPS tests or TEMPS style tests, costs would be of the order of 1 million dollars.

#### 5.1.3.3 Duration of Test

Technique 3, employing the use of high level pulse testing, would require a threat level pulse simulator such as TEMPS. Since POE direct drive (Pulse) is also to be employed, additional pulsers would be required. For a high level pulse test site, preparation and simulator assembly require approximately one month. This includes erection of simulator pulser and radiating antenna, data reduction facilities, data acquisition facilities, administrative office space, and installation of utilities. A similar period of time would be required at the end of the program to remove the simulator and associated equipment. Based upon previous test efforts at Polk City, Florida, and Delta, Utah, a minimum test period of six months would be required. During the six month period, both High Level Pulse radiation and POE Direct Drive (P) could be accomplished. As in past tests utilizing TEMPS, POE Direct Drive testing could be accomplished concurrent with TEMPS on a noninterference basis. Inasmuch as Site 1 is a very large, functionally complex facility, with a large number of differing types of POEs, a six month test program is considered a minimum test.

#### 5.1.3.4 Practicality

Any test of a large complex facility using threat level simulation techniques requires the application of considerable resources, both in terms of hardware and manhours required.

A considerable number of agencies inevitably become involved in a threat level simulation test. At a minimum, the using agencies, sponsoring agency, the simulator owner agencies, their contractors, and the analysis agency and their contractors would be involved. In typical past EMP assessment programs, a test working group was formed with representatives from all of the participating agencies as members. In preparation for a test the test working group began meetings as early as three to six months in advance of the test. Test planning and coordination must begin a minimum of six months in advance of such a large scale test program.

The test facilities required for such a program are typified by the inventory of the full scale TEMPS facility. This facility consists of:

1. The TEMPS pulser, with antenna
2. The TEMPS command and control van
3. A TEMPS maintenance man
4. A data acquisition instrumentation van
5. An instrumentation calibration van
6. A data reduction van
7. An equipment van
8. Administration, engineering and office space  
(up to 5 additional mobile office trailers)

For a test program utilizing a threat level radiating simulator other than TEMPS, a similar complement of material would be required. (The In-Place Program using SIEGE required slightly more resources).

The transportation requirements for such a program, although varying largely with the objectives and scope of the program, contain as a minimum the use of 10 to 20 large semi-trailers to transport the facility equipment and the vans associated. Transportation outside CONUS becomes progressively more complicated.

#### 5.1.3.5 Interference with Site

The installation of any threat level simulator requires extensive facilities construction in the vicinity of the site. However, all of these efforts involve only temporary modifications to the site; at the termination of test all facilities can be removed, and the site restored to its original condition. During a test of this nature access to the site and to the site operating personnel would be required for the data acquisition engineers and technicians.

During a threat level test using either threat level radiated simulation, or high level POE direct drive, the possibility of functional interruption of site activity exists. Although it is impossible to accurately predict, in a newly constructed EMP hardened site, the probability of more than occasional transient interrupts would be very small. It is anticipated that this site could be maintained operational throughout such a test.

There are no unique personnel safety hazards encountered during EMP testing. There is a high voltage electrical hazard present in the vicinity of a pulser(s). However, the site operating personnel are not exposed to these hazards. There are no known radiation hazards associated with EMP testing. However, some communications contractors, such as AT&T, do not allow their personnel to be exposed through electrical fields in excess of 5 kV per meter. Should pretest predictions or early low level testing indicate that such fields will exist in areas where the site operating personnel are required to be, shield rooms can be installed in those areas so that site operating personnel can be protected during actual high level testing.

#### 5.1.4 Site 1 - Technique 4

Technique 4 consists of analysis and POE direct drive (P). The use of only direct drive testing increases the assessment confidence only in the area of internal propagation and nonlinear threat level response of the POE electrical surge arrestors. The assessment confidence would be limited to the analysis confidence in the areas of shielding, thresholds and POE coupling.

##### 5.1.4.1 Assessment of Confidence

5.1.4.1.1 Analysis. The accuracy of the analysis for Technique 4 is the same as for Techniques 1, 2, and 3, that is 25 dB.

5.1.4.1.2 POE Direct Drive. The POE direct drive test increases the assessment accuracy by 10 dB, from 25 to 15 dB total.

##### 5.1.4.2 Costs

The cost of the analytic assessment is the same as discussed above. The cost of the POE direct drive test is the same as discussed above.

##### 5.1.4.3 Duration

The duration of a POE direct drive test, as discussed above, would be from eight weeks to four months.

#### 5.1.4.4 Practicality

As discussed above, implementation of POE direct drive tests is an extremely practical technique in that few agencies are involved and all of the hardware and expertise required for this program currently exists and could be shipped to the site with minimum problems.

#### 5.1.4.5 Interference with Facility

As discussed above, there would be no interference with the operation of the facility with the exception that support from site personnel would be required for locating drive and measurement points and there always exists the possibility during threat level direct drive testing that the site operations may be briefly interrupted.

#### 5.1.5 Site 1 - Technique 5

Technique 5 consists of analysis, CW radiation, and subsystem testing.

##### 5.1.5.1 Accuracy of Data

5.1.5.1.1 Analysis. The analysis approach to be used in Technique 5 is identical to that used in Technique 1. Hence, from Paragraph 1.1.1.1. The one sigma error associated with an analytic assessment for this type of site is 25 dB.

5.1.5.1.2 CW Radiation. As mentioned earlier in the evaluation of Technique 2, there are two types of potential CW radiation tests which could be performed. Since the purpose of this CW radiated test is to verify the integrity of the electromagnetic shield, the recommended technique is to locate the radiating elements or antennas inside the site and measure the resultant fields outside the site. In order to cover the band with of interest several styles and sizes of antennas would be required. The accuracy of this type of test would be plus or minus 3 dB.

The standard method of illuminating a site with radiated CW from a vertical monopole and measuring fields, currents, and voltages inside the site is not recommended for application at Site 1. This is because the

anticipated shielding of Site 1 is conservatively estimated to exceed 80 dB, and the dynamic range of this technique is insufficient to make meaningful measurements and facilities with this much attenuation.

5.1.5.1.3 Subsystem (Black Box) Testing. Black box testing at the subsystem level improves the accuracy of the assessment by reducing the uncertainty in the thresholds of the devices, and by obviating the need to model the coupling path from the subsystem level to the circuit level. This results in a total of 5 dB improvement in the assessment prediction.

5.1.5.1.4 Overall Technique Accuracy. Inasmuch as the recommended CW test is a site shielding validation test, and not a transfer function measurement, there is no quantitative increase in the accuracy of the predictions resulting from this test. The increased accuracy resulting from the subsystem testing is 5 dB. The overall error of the assessment prediction generated using Technique 5 would therefore be improved from approximately 25 dB to approximately 20 dB for one standard deviation.

#### 5.1.5.2 Costs

The analysis cost for a 25 dB assessment of Site 1 lies between \$24,000 and \$96,400. The approximate cost for measuring the attenuation of the facility from inside to outside utilizing a CW radiation technique would be approximately \$28,000. Approximate cost of subsystem (black box) testing assuming a total of 10 boxes to be tested would be approximately \$65,000. By simple addition of the above component cost can be seen that a facility assessment of Site 1 using Technique 5 would fall between illuminants of \$117,000 and \$189,000.

#### 5.1.5.3 Duration of Test

It has previously been estimate that a CW radiation test on Site 1 could be performed in one month, with an additional 2-4 weeks for equipment setup and tear down. A subsystem (black box) test program for Site 1 components, assuming testing of 10 boxes would take 10 months.

#### 5.1.5.4 Practicality

This would be an extremely practical technique to implement. Only a limited number of agencies are required, all of the hardware that is required currently exists, and several government agencies and civilian contractors have the required expertise to perform both the CW and the Subsystem tests.

#### 5.1.5.5 Interference with Site

There would be little or no interference with setup operation. Support from site personnel would be minimal in that no test points within the facility operating equipment would be utilized. There is a possibility, small but non-zero, that the levels of radiation involved in a CW test from inside the facility may cause some interference with site equipment resulting in transient interrupt.

#### 5.1.6 Site 1 - Technique 6

Technique 6 consists of analysis combined with high level pulse radiation.

##### 5.1.6.1 Accuracy of the Data

The total accuracy of an assessment of a well shielded and hardened facility such as Site 1 based on Technique 6 would be limited to the accuracy involved in the analytic assessment. Because of the limited dynamic range of a TEMPS style test, compared to the building shielding, accurate data to refine the predictive model could not be reliably obtained. Hence, a TEMPS style test would be used primarily to detect leaks or other deviations from design goals. Technique 6 then is essentially a 25 dB analytic assessment program whose results might be verified or disproven by a TEMPS test. It is difficult to quantify the resultant reduction in uncertainty. The assessment confidence resulting from the application of Technique 6 would then be 25 dB.

##### 5.1.6.2 Costs

The rental cost for a TEMPS style simulator amounts to roughly 1 to 1.5 million per year. A go, no-go style test such as envisioned would last

between 3 and 5 months. Current engineering estimate is approximately 3 months, however, because costs do not scale linearly, and because the exact cost estimates would have to be based on test objectives and transportation cost, exact cost estimates for Site 1 would have to be determined. However, a TEMPS style test combined with detailed analysis effort, would result in cost of the order of \$500,000.

#### 5.1.6.3 Duration

Because the high level pulse radiation test envisioned for Site 1, Technique 6 is essentially to go, no-go style test a program much shorter than the 6 month program discussed in Paragraph 5.1 is envisioned. However, inasmuch as Site 1 is a large complex site even an abbreviated go, no-go style test could not be performed in less than 3 months.

#### 5.1.6.4 Practicality

As mentioned earlier, any test of a large facility using threat level simulation techniques requires considerable resources, (see Paragraph 5.1.3.4). Hence, Technique 6 is considered to be an impractical test program. The results acquired, in terms of increased confidence or increased accuracy in the assessment do not compare favorably with the high cost and large resource requirements.

#### 5.1.6.5 Interference with Site

The installation of any threat level simulator requires extensive facilities construction in the vicinity of the site. However, all these efforts involve only temporary modifications to the site; at the termination of tests, all facilities can be removed, and the site restored to its original condition. During a test of this nature access to the site and to the site operating personnel would be required for data acquisition engineers and technicians.

During a threat level test the possibility of functional interruption a site activity exists allowing possible to predict accurately, in a newly constructed EMP hardened site, probability of more than occasional transient interrupts would be very small.

## 5.2 SITE 2

Generic Site 2 is characterized as a buried shielded building. In general, the building may or may not have an antenna tower present; it has few cables which are buried and shielded, has EMP shielding around the building, has few antennas and has no special EMP protection on the penetrations of the cables. The generic Site 2 model is shown in Figure 2-2. An actual site representative of this class is shown in plan view in Figure 2-6. There are no waveguides, horns, or tower at this site, nor are there any soft CHU-1085 antennas. There are four hardened antennas (CA-3018H). They are located approximately 285 feet due west of the main building and are placed on two separate towers. The cables from each of the hard antennas enter the ground at the antenna base. The cables then run approximately 300 feet to the building. There are three L-4 cables approximately 2" in diameter and each has a 1/8" lead shield covered by a 1/8" insulation layer. In addition to the hard antennas listed above, there is one FM radio antenna. There is one 1-1/4" diameter local telephone line cable which enters the building. This telephone cable is buried. The main power lines approach the site from the northeast above ground. At a point 150 feet from the northeast corner of the building the power lines enter the ground. Power cables are each encased in a conduit. Each conduit is 4" in diameter. These conduits are buried approximately one foot underground and they run to the power transformer located at the northeast side of the building. Table 2-5 summarizes the antenna and cable penetrations to actual Site 2.

The test techniques selected for application on Site 2 include:

1. Technique 2 - Analysis, CW Radiation, POE Direct Drive.
2. Technique 3 - Analysis, High Level Pulse Radiation POE Direct Drive (P)
3. Technique 5 - Analysis, CW Radiation, Subsystem (Black Box) Testing
4. Technique 6 - Analysis, High Level Pulse Radiation

5. Technique 7 - Analysis, Low Level Pulse Radiation, POE Direct Drive (P)
6. Technique 8 - Analysis, CW Radiation, POE Direct Drive (CW), POE Direct Drive (P)

Technique 2 would employ CW radiation to quickly test site shield integrity. As there are few antennas and external cables associated with this site, direct drive of the POEs to those levels predicted by what might be anticipated to be an only moderate analysis effort would complete the assessment technique.

Technique 5 would also use CW radiation to test site shield integrity. Due to the number and simplicity of antennas and cables a modest analysis effort would be anticipated to estimate to and through the POEs. No sophisticated ESA protection exists for this site so that subsystem tests could then be used to predict upset/damage thresholds and margins of safety.

Technique 7 was selected primarily because for the particular site model there was reason to believe that the site shield may have been less than adequate. Therefore, while Site 2 has a shield, its integrity is very uncertain. This hypothesis is certainly in harmony with the fact that ESA protection is not provided. Low level pulse radiation is then a viable test approach for Site 2. Because of the relative simplicity of the site, a modest analysis effort would be anticipated for coupling predictions, followed by direct drive of the POEs to predicted levels.

Technique 8 is identical to Technique 2, with exception of additional CW direct drive testing. This additional feature is particularly applicable because of the lack of ESA protection of Site 2. As in other test programs, it would extend the understanding of the coupling mechanisms or transfer functions into the site.

5.2.1 Site 2 - Technique 2

Technique 2 consists of analysis, CW Radiation, and POE DirectDrive.

5.2.1.1 Accuracy of Data

5.2.1.1.1 Analysis. An analysis of this type of site would consist of describing the local electromagnetic environment, describing the external POE coupling, assessing the propagation of POE coupled signals inside the building shielding, and determining the failure and upset thresholds of the critical interfaces.

The electromagnetic environment at the site can be predicted as a function of depth and soil parameters to within  $\pm 5.5$  dB. Pretest predictions for the magnitude of currents and voltages coupled to buried POE cables are accurate to within  $\pm 9$  dB. If we assume that the buried building shielding is well designed and has not deteriorated dramatically since construction, then the field inside the building can be predicted to within  $\pm 6$  dB (ignoring the effects of internal structure and equipment). However, since Site 2 has not had a recent EM shielding effectiveness test, and defects in shielding are frequently impossible to detect visually, large variances in internal fields could be encountered. This will be reflected in increased uncertainties in the internal coupling models. Degradation of predictions at critical interfaces is estimated at 6 dB. Hence, the voltage and currents seen at each of the critical interfaces can be predicted based upon the propagation from the point of entry to the interface only to within  $\pm 28$  dB. From past EMP predictions and subsequent testing, the value of the damage and upset thresholds can be predicted analytically by simple hand analysis or from existing data bases to within an accuracy of  $\pm 30 - 5$  dB.

5.2.1.1.2 CW Radiation. For this site, a standard EMP type CW test is assumed. In this type of test, a site is illuminated by a known CW field and transfer functions are measured directly. In the discussion of CW radiation testing in Paragraph 5.1, it was noted that using a 10 watt radiator outside the building, and assuming building attenuation of 80 dB, B-dot signals within the building would be of the order of a few millivolts. Hence, this type of a test would be adequate to verify that the combined building and earth shielding at Site 2 were at least 80 dB. For signals at frequencies which were not attenuated by at least 80 dB, measurable data in excess of a few millivolts would be taken

taken inside the building. Therefore, since it is the objective of a CW radiated test to verify that the shielding integrity of the building is in excess of 80 dB, this type of test would be adequate. Because the signal to noise ratio, when measuring millivolt level signals inside a communication site are less than 20 dB the accuracy of the data would be questionable (errors of the order of magnitude of 10 dB could easily occur). Thus, if the total attenuation of the earth overburden and the building shielding is in excess of 100 dB, this technique could not accurately measure the transfer function. However, since 80 dB is considered adequate shielding, the inability to measure transfer functions is unimportant and the errors mentioned above are acceptable.

5.2.1.1.3 POE Direct Drive (P). As stated in 5.2.2.3, individual voltage and current measurements in a direct drive pulse test of a POE can be made within  $\pm 1.6$  dB. Average standard deviation for voltage and current transfer functions in this type of test is  $\pm 2.5$  dB.

5.2.1.1.4 Overall Accuracy - Technique 2. For an older site whose EM shielding has not been recently tested, variance between specified shielding value and actual shielding value can be quite large. Errors up to 40 dB (at some frequencies) in the estimate of shielding effectiveness could be encountered. This would introduce additional errors in interior coupling model. Although, it is difficult to quantify these errors, an estimate of 6 dB has been assumed. Therefore, it is estimated that a CW test which verifies shielding, or pinpoints defects would increase assessment accuracy by 6 dB narrowing uncertainty in shielding and an additional 3 dB by contributing to refined model parameters.

When combined with POE direct drive (P), which further reduces errors in internal coupling, an assessment accuracy of 13 dB could be achieved.

#### 5.2.1.2 Cost Factors

5.2.1.2.1 Analysis. Given that Site 2 is a buried, shielded building, the coupling analysis for interior coupling paths would be limited to propagation from points of entry to the critical interfaces. Since it is also true that there

are a limited number of points of entry to Site 2, the coupling of the external coupling to the POEs could be analyzed in a fairly simple straightforward fashion. Because of the relative simplicity of the geometry of Site 2 and of the coupling analysis, an abbreviated type assessment of Site 2 should be adequate to yield an assessment with approximately 32 dB accuracy. Such an assessment would require approximately 2 man-months to plan, perform and document a site survey; approximately 6 man-months to model, analyze, and make predictions; 1 man-month to report; and some travel and computer costs. Such an assessment would cost between 25 and 35 thousand dollars.

5.2.1.2.2 CW Radiation. Assuming that the appropriate equipment is readily available as GFE, and that site access will not provide undue delay, it should be possible for one technician and one engineer to set up the test equipment, complete the test, and remove the test equipment in four weeks. Thus, there would be 160 hours of engineering time and 320 hours of technician time. It will require an additional two weeks of engineering time and one week of technical publications time to prepare a report. Thus, the total cost of such a simple CW radiated test would involve six weeks of engineering time and five weeks of technician time. At \$25 and \$15 per hour respectively, this totals to \$9000. This test does not include the cost of any analysis which would be done under the analysis section.

5.2.1.2.3 POE Direct Drive (Pulse). Again, given that the test equipment is provided as GFE and that undue delays are not encountered because of site access problems, the POE direct drive test on a fairly simple facility with limited numbers of POEs could be accomplished by one engineer and two technicians in approximately one month. An additional two weeks in engineering time would be required for test reporting. An additional two weeks technician time would be required for a technical publications support in preparing the test report. Thus, a total of 400 technician hours and 240 hours of engineering would be required. At a cost of \$15-\$25 per hour respectively, the total cost would be \$12,000. Once again, this does not include data analysis or data reduction.

#### 5.2.1.3 Duration

In evaluating the duration of a hypothetical test program it has been assumed that the test facility and test hardware would be GFE and the test facility would be available and the only minimum modifications to the facility would be required so that no undue delays would be incurred.

5.2.1.3.1 CW Radiation. A simple CW radiation test involving a measurement of up to 30 transfer functions could be performed in approximately two weeks. Should additional transfer functions be required up to four weeks might be expended in this type of testing.

The POE direct drive (pulse) test program could be performed on a facility such as Site 2 in a two month period.

#### 5.2.1.4 Practicality

This would be an extremely practical technique to implement. Only a limited number of government agencies are required, all of the hardware that is required currently exists and several government agencies or civilian contractors have the required expertise to perform the tests. The CW radiation test would require only one contractor or government agency in addition to the facility operator. The direct drive program would require one agency or contractor. Very little, in the way of data reduction and processing time or equipment would be required; this part would be provided by the analysis contractor. Shipping of equipment and simulators would also be a practical matter since no extremely large or bulky simulators or instrumentation is contemplated.

#### 5.2.1.5 Interference with Site

The interference with the site operation occasioned by these tests would be minimum. There would be few or no site modifications required, there would be no earth work required. Support from site personnel would be required in locating and connecting to the drive and test points during both the CW and POE tests. During POE direct drive at high level, there does exist a possibility of brief interruptions of the site. For this type there is no radiation hazard and only routine safety hazards that are connected with any high voltage pulse test.

#### 5.2.2 Site 2 - Technique 3

Technique 3 consists of Analysis, High Level Pulse, and POE Direct Drive (Pulse).

##### 5.2.2.1 Accuracy of Data

5.2.2.1.1 Analysis. As in Technique 2, an abbreviated assessment of Site 2 could be performed with an accuracy of 32 dB.

5.2.2.1.2 High Level Pulse Radiation. The objectives of a high level pulse radiation test at a facility such as Site 2 would be: 1) determine electromagnetic attenuation provided by the building shielding, and 2) measure the electromagnetic and functional response of the facility to a threat level pulse. Site 2 is both buried and shielded, and it is questionable whether sufficient signal level would be attainable inside the site to make an accurate measurement to satisfy objective 1. Reflection and attenuation losses of 15 dB can be anticipated. A conservative estimate of 60 dB shielding provided by the seven ounce copper sheath on the building is assumed. Hence, a total electromagnetic field attenuation of approximately 75 dB is to be anticipated at Site 2. Even if there should be large deficiencies at some frequencies or in some locations within Site 2 it is extremely unlikely that adequate data would exist for an accurate quantitative determination of the field within the building.

Because Site 2 is both buried and shielded, the primary coupling factor to the critical interfaces will be excitation of the POEs. Inasmuch as the penetrations at Site 2 are not treated with surge arrestors or filters, these penetrations are frequently confined to the local area (e.g., area lighting) a TEMPS environment would provide adequate field levels to perform a meaningful test of the coupling from the field to the critical circuits on the interior of the building. Post test assessment accuracies after a high level pulse test are of the order of 12-15 dB.

5.2.2.1.3 POE Direct Drive (Pulse). Because of the limited size of the coverage area of the TEMPS field, as compared to a HA field excitation of the external coupling paths to the penetrations will not achieve comparable levels. When used in conjunction with a TEMPS test, POE Direct Drive (Pulse) overcomes this deficiency.

5.2.2.1.4 Overall Technique Accuracy. The combination of Analysis, High Level Pulse Radiation, and POE Direct Drive (Pulse) was used on the AUTOVON sites at Polk City, Florida and Delta, Utah. By verifying and refining predictive models of those sites, it is felt that the post test predictions concerning these sites are accurate to within approximately 10-12 dB. By comparison it is assumed that Technique 3 could be applied to Site 2 with equal accuracy yielding a total assessment with 10-12 dB errors or uncertainties.

#### 5.2.2.2 Costs

A high level pulse radiation simulator similar to the TEMPS costs 1 to 1.5 million dollars per year. Inasmuch as Site 2 is fairly a simple site, both functionally and geometrically, a pulse test duration of approximately 3 months is assumed. However, because simulator operating costs do not scale linearly a high level pulse radiation test program would cost on the order of \$500,000. When combined with the analysis and POE direct drive costs, a total assessment program of approximately \$600,000 would be involved in the use of Technique 3.

#### 5.2.2.3 Duration

The high level pulse radiation test would require 3 months. A POE direct drive pulse test program would require approximately 2 months. By combining the two and taking advantage of common data requirements the test program could probably be compressed to 4 months. An additional 2 months would be required for setting up and tearing down the equipment.

#### 5.2.2.4 Practicality

Any test using threat level simulators requires considerable resources. Thus, such a test ranks low on a scale of practicality. Particularly when compared to the other techniques which yield assessment accuracies comparable to Technique 3 at much less cost and effort.

#### 5.2.2.5 Interference with Site

Extensive physical modifications are required in the vicinity of the site to house the simulator facilities. However, all of these modifications are temporary and the site can be returned to its original configuration at the end of a test program. During both High Level Pulse Radiation and POE Direct Drive testing assistance would be required from the site personnel in locating and accessing measurement points. During any High Level Pulse test the possibility of transient interrupts or damage exists.

#### 5.2.3 Site 2 - Technique 5

Technique 5 consists of analysis, CW radiation, and subsystem (black box) testing.

##### 5.2.3.1 Accuracy of Data

5.2.3.1.1 Analysis. As in Technique 2, an abbreviated assessment type analysis of Site 2 could be performed with an assessment confidence interval of  $\pm 32$  dB (1 sigma).

5.2.3.1.2 CW Radiation. As noted above, the accuracy of CW radiation is within 1 dB. Because of reduced error in internal coupling and model parameterizing, overall assessment is improved by 10 dB.

5.2.3.1.3 Subsystem ("Black Box") Testing. As noted in Paragraph 5.1.1.1.3 for typical classes of discrete solid state component type hardware, statistical variation of damaged thresholds is the limiting factor in the accuracy of black box testing. This error is in the vicinity of  $\pm 3$  dB, which results in 2 dB improvement over the 5 dB analysis error.

5.2.3.1.4 Overall Accuracy - Technique 5. Starting with a 32 dB analytic assessment, the additional accuracy provided by the CW and subsystem test is 17 dB. Thus, the overall accuracy of Technique 5 applied to Site 2 is 15 dB.

#### 5.2.3.2 Cost Factors

5.2.3.2.1 Analysis. As noted above, an abbreviated type assessment within a one sigma confidence interval of 22 dB can be performed for approximately 25 to 30 thousand dollars.

5.2.3.2.2 CW Radiation. As noted above in Paragraph 5.2.1, a CW radiation test of a Site 2 facility would cost approximately \$9,000.

5.2.3.2.3 Subsystem Tests. As noted in Paragraph 5.1, subsystem testing can be performed at the Air Force Weapons Laboratory PUDD Facility for a typical test cost of \$6,310 per black box. Assuming four black boxes are to be tested, this would incur a total cost of approximately \$25,000.

#### 5.2.3.3 Duration of Test

It was noted before that the CW test would require approximately two weeks of on-site facility time. The black box test which would require approximately one month per box would require a four month period of time.

#### 5.2.3.4 Practicality

Technique 5 would be an extremely practical and simple technique to implement. Very few agencies would be involved. The test facilities are reasonably small and simple, are currently existent, and are normally available for relatively small simple tests such as the one proposed.

#### 5.2.3.5 Interference with Facility

The only portion of Technique 5 which takes place on site would be the CW radiation test. This would involve no interference with the operation of the facility. However, facility personnel support would be required to locate and connect to measurement test points.

5.2.4 Site 2 - Technique 6

Technique No. 6 consists of analysis and high level pulse radiation.

5.2.4.1 Accuracy of Data

5.2.4.1.1 Analysis. As previously stated, an analytic assessment of Site 2 would have an error bound of 32 dB.

5.2.4.1.1 High Level Radiated Pulse. As stated previously, data accuracy in high level pulse testing is  $\pm 2.5$  dB, and the post test assessment accuracies are from 12-15 dB.

5.2.4.2 Costs

A high level pulse test of the site would involve costs of the order of \$500,000 (see paragraph 5.2.2.2).

5.2.4.3 Duration

A high level pulse test at Site 2 would require approximately three months.

5.2.4.4 Practicality

Any test using high level threat simulators requires considerable resources. Thus, such a test ranks low on a scale of practicality. Particularly when compared to the other techniques which yield assessment accuracies comparable to Technique 3 at much less cost and effort.

5.2.4.5 Interference with Site

Extensive physical modifications are required in the vicinity of the site to house the simulator facilities. However, all of these modifications are temporary and the site can be returned to its original configuration at the end of a test program. During both High Level Pulse Radiation and POE Direct Drive testing assistance would be required from the site personnel in locating and accessing measurement points. During any High Level Pulse test the possibility of transient interrupts or damage exists.

#### 5.2.5 Site 2 - Technique 7

Technique 7 consists of analysis, low level pulse radiation, and POE direct drive (pulse).

##### 5.2.5.1 Accuracy of Data

5.2.5.1.1 Analysis. As noted before, an analytic assessment of a type 2 facility would provide a 32 dB assessment with a one sigma confidence.

5.2.5.1.2 Low Level Pulse Radiation. The measurement techniques used in a low level pulse radiation test are identical to those used in a high level pulse radiation simulator test. Therefore, currents can be measured with an accuracy of  $\pm 1.5$  dB, voltages with an accuracy of  $\pm 2$  dB. The average one sigma confidence interval for a transfer function is  $\pm 2.5$  dB.

5.2.5.1.3 POE Direct Drive (P). As noted above the accuracy of data taken in POE Direct Drive (P) testing is 2.5 dB.

5.2.5.1.4 Overall Technique Confidence. Technique 7 was selected because for this particular site there was reason to believe that the site shield might have been less than inadequate. Thus, although the site has a shield, its integrity is uncertain. Because the site shielding integrity is uncertain, it was hypothesized that low level pulse testing would be a reasonable technique for this site. However, since it is not known for a fact that the shield is inadequate, it is quite possible that a low level pulse test would not yield useful data. Because the dynamic range of the low level pulse test is limited, a test which gave null or zero results would not be indicative of anything at all. A high level pulse test with a large dynamic range with similar results would indicate that the site shielding was adequate. The absence of measurable signal levels is a positive indication that the site is adequately hardened. This is not true in the case of a low level pulse test. Thus, there is a high probability that errors in a low level pulse test will exceed 40 dB, when extrapolated to threat. Thus, Technique 7 is not considered an acceptable technique, and will not be evaluated further.

#### 5.2.6 Site 2 - Technique 8

Technique 8 consists of CW radiation, POE direct drive (CW), and POE direct drive (pulse). Technique 8 is identical to Technique 2 with the addition of CW direct drive testing. CW direct drive testing would not add any more insight to the sites coupling mechanism for hardness than would pulse type POE direct drive tests. However, if the CW direct drive testing were accomplished in conjunction with or prior to analytic effort, it would considerably enhance the analysis confidence or reduce the analysis cost. The limited CW testing envisioned would be accomplished by the analysis team during their site survey. A detailed evaluation of Technique 8 is not included here because it is considered equivalent to Technique 2.

#### 5.3 SITE 3

Site 3 is characterized as a buried unshielded facility. The buried building is constructed of reinforced concrete hardened to design an overpressure of 50 psi. The top of the building is 2 feet below the surface of the earth. There is a 350 foot high radio tower. The techniques chosen for evaluation for potential use on Site 3 include:

- Technique 2 Analysis; CW Radiation; POE Direct Drive (P)
- Technique 3 Analysis; High Level Pulse Radiation; POE Direct Drive (P)
- Technique 5 Analysis; CW Radiation; Subsystem ("Black Box") Testing
- Technique 6 Analysis; High Level Pulse Radiation
- Technique 7 Analysis; Low Level Pulse Radiation; POE Direct Drive (P)
- Technique 8 Analysis; CW Radiation; POE Direct Drive (CW); POE Direct Drive (P)

Site 3 is nominally an unshielded facility. However, to determine the feasibility of any radiated test whether pulse or CW, some data on the shielding effectiveness of the facility must be known. Table 5-4 summarizes the data from the SAFCA shielding effectiveness tests if we assume that this buried building at Site 3 is an average concrete building. Its attenuation will be similar to the mean attenuation of the buildings tested in the SAFCA study, i.e., 27 dB, with an error of 27 dB, 1 standard deviation.

Table 5-4  
Summary of SAFCA Shielding Effectiveness Data for Various Sites

Location	Construction	Measured Attenuation (dB)	Average Attenuation (dB)	$\delta$
Shiner	Concrete	5-21	13	14
New Hope	Concrete	10-30	20	7
Midlothian	Precast Tilt Up	11-33	22	5
Wallace	Cast in Place	16-37	26	1
Longmont	Case in Place	25-48	36	9
Vega	Case in Place	38-54	46	19
Mean Attenuation		27 dB		
Standard Deviation ( $\sigma$ )		27 dB		

### 5.3.1 Site 3 - Technique 2

#### 5.3.1.1 Accuracy of the Data

5.3.1.1.1 Analysis. An analytic assessment of Site 3 would be accurate to within  $\pm 25$  dB.

5.3.1.1.2 CW Radiation. Assuming that the attenuation provided by the rebar in the structure of the buried building would be 27 dB, and that the attenuation provided the building by being buried approximately 1 meter below the surface is 15 dB, then the total shielding provided for Site 3 is 42 dB. Under these circumstances it is reasonable to perform a CW radiation test. Should the shielding prove to be considerably less than 42 dB then accurate transfer functions

for many of the critical interfaces can be measured directly, thus providing considerable improvement in the accuracy of the assessment. Should the total attenuation prove to be considerably more than 42 dB, then a CW test with null results would also be a meaningful test and provide additional confidence in the assessment by eliminating errors connected with internal coupling of fields. In either event an improvement in the prediction accuracy of 10 dB would be achieved.

5.3.1.1.2 POE Direct Drive. Inasmuch as Site 3 has a large number and variety of penetrations, the electromagnetic response of Site 3 will be, to a large extent, controlled by POE coupling. A high level direct drive pulse test of the POEs would eliminate the uncertainty connected with coupling from the POE to the circuit level. Thus, the total prediction uncertainty could be reduced from 22 to 10 dB.

5.3.1.2 Costs

5.3.1.2.1 Analysis. Because Site 3 is relatively more complex than Site 2 a more detailed lengthy analytical assessment would be required. This is caused by the fact that there exists a possibility of coupling of fields in internal conductors and because there are additional POEs at Site 3 not encountered at Site 2. Thus, an analytical assessment of Site 2 would yield an analytic assessment of 22 dB accuracy for a cost lying between 50 and 75 thousand dollars.

5.3.1.2.2 CW Radiation. Again, because of the increased complexity of Site 2, and because of the greater possibility of significant internal fields, a more complex CW test would be required. It is estimated that one technician and one engineer could set up the test equipment, complete the test and remove the test equipment in eight weeks. Thus, there would be 320 hours of engineering time and 320 hours of technician time. In addition, four weeks of engineering time and two weeks of technical publications time are required to prepare a report. Thus, the total cost would be between 18 and 20 thousand dollars. This estimate does not include the cost of any pretest analysis or any data reduction and analysis.

5.3.1.2.3 POE Direct Drive (P). It is estimated that a POE Direct Drive (pulse) at a site such as Site 2 would require the efforts of one engineer and two technicians approximately two months to set up the test instrumentation, complete the tests, and remove the instrumentation. An additional one month of engineering time would be required for data processing and reporting and an additional month of technician time would be required for technical publications to prepare a test report. Thus, a total of approximately 800 technician hours and approximately 480 engineering hours would be required. The total cost for such an effort would be \$24,000.

5.3.1.3 Duration

In the preceding two paragraphs, it was stated that approximately two months would be required for a CW test and approximately two months for a POE direct drive test. Although the excitation source for these tests are different in nature there would be considerable overlap in the data requirements of both programs. Therefore, it is assumed that both tests could be run concurrently on a noninterference basis with a time savings of approximately one month. Thus, it is estimated that a total test duration for a Technique 2 would be three months on-site.

5.3.1.3.1 Practicality. On a site such as Site 3, Technique 2 would be a practical test technique to implement. Only a limited number of government agencies would be required, the using agency, the sponsoring agency, and a testing agency or contractor. All of the hardware required for both types of tests currently exists and several government agencies or civilian contractors have the required expertise. On-site data reduction would be at a minimum since this service would be provided by the analytic assessment contractor. Shipping of bulky equipment would be minimized since the data acquisition and excitation equipment neither extremely large or extremely bulky.

5.3.1.3.2 Interference with Facility. Technique 2 would not involve interruption of facility operation nor would it involve extensive facility modification or earth work. The services of on-site personnel would be required to locate measurement points and direct drive points. As with any threat level direct drive test, the possibility of transient interruptions and potential damage exist.

There would be no operational interference created by a CW radiation test other than the requirement for personnel.

#### 5.3.2 Site 3 - Technique 3

Technique 3 consists of analysis, high level pulse radiation and POE direct drive (P).

In the evaluation CW radiation testing for Site 3, it was stated that the most probable value of attenuation of the building at Site 3 is 27 dB with a 1 sigma standard deviation of 27 dB. It must be kept in mind that this is a fairly crude estimate based on limited data. The actual shielding value of the building in Site 3 is completely unknown. It is not known whether the dynamic range of a high level pulse radiation test would be sufficient to acquire meaningful data.

A high level pulse radiation test program is always a costly undertaking. Such a program ranks high in cost, low in practicality, and high in interference with site operations.

In view of the above, a high level pulse radiation test cannot be recommended at this time. Additional data in the form of CW testing or analytic predictions should be acquired and used as a bases for a proper determination of a test no-test decision. Until such data is made available, it is impossible to quantitatively determine the accuracy of the results of a high level pulse radiation test on a facility such as Site 3.

Application of the remainder of the evaluation criteria will not be performed on Technique 3. It can be stated, however, based on previous analyses of high level testing programs, that Technique 3 would rank high in cost and low in practicality.

#### 5.3.3 Site 3 - Technique 5

Technique 5 consists of analysis, CW radiation, and subsystem black box testing. Technique 5 relies primarily upon the analytic assessment predictions to determine electromagnetic site response. The use of CW radiation testing would enhance the accuracy of those predictions. Subsystem

black box would be utilized to determine the damage and upset thresholds of the critical equipments. The site vulnerability assessment would then be made by comparing the CW refined analysis predictions with the black box test thresholds.

#### 5.3.3.1 Accuracy

5.3.3.1.1 Analysis. An analytic assessment of Site 3 would be accurate to within  $\pm 25$  dB.

5.3.3.1.2 CW Radiation. The accuracy of the analytic assessment statement would be enhanced by CW testing to 12 dB.

5.3.3.1.3 Subsystem (Black Box) Testing. Given that the accuracy of upset and damage thresholds determination based on analysis is 5 dB and that after a test program the uncertainties in the test program combined with the statistical spread in the manufacturing tolerances given a post test accuracy of 3.4 dB, then an assessment based on subsystem test results will on the average be 1.5 dB more accurate than one based upon hand analysis and prediction alone. The 5 dB improvement normally associated with subsystem testing is not found here because the coupling from subsystem to circuit is already in the CW test.

5.3.3.1.4 Overall Technique Accuracy. Given that the electromagnetic response based on analysis and CW test accuracy to within  $\pm 12$  dB and the accuracy of the thresholds based upon subsystem tests or  $\pm 3.4$  dB, then the uncertainties added in quadrature equal 12.5 dB.

#### 5.3.3.2 Costs

The costs of the analysis and CW radiation portion of Technique 5 are the same as in Paragraph 5.3.1, Technique 2, that is \$50,000 to \$75,000 and \$18,000 to \$20,000, respectively. The cost of subsystem black box testing at the PUDD Facility is as stated in Paragraph 5.1, \$6,310 per box. It is anticipated that approximately three to five types of boxes would be new or would contain solid state devices which have not been tested before, the total cost of a subsystem black box test would lie between \$18,000 and \$31,000.

#### 5.3.3.3 Duration of Test

The CW radiation test would require three months occupancy of the site. The subsystem black box test would not be run on-site but at the PUDD Facility and could be run concurrent with the CW radiation test. These tests would also take approximately three months. Thus, the total test duration for Technique 5 would be three months.

#### 5.3.3.4 Practicality

Technique 5 would be a very practical test to implement. However, it would in fact, be less practical than Technique 2 because a black box test would require that black boxes be made available by the using agency, transported to Albuquerque, and subjected to possibly damaging testing at the PUDD.

#### 5.3.3.5 Interference with Site

Inasmuch as the only on-site testing would be CW radiation testing, Technique 5 would involve very little disruption to routine site activities. Since there is no probability of transient interruption caused by the low level CW radiation, the only interference with the site would be access required for data acquisition personnel and the use of on-site operations personnel to assist in locating measurement points.

#### 5.3.4 Site 3 - Technique 6

Technique 6 consists of analysis and high level pulse radiation. As stated in Paragraph 5.3.2, the uncertainty in the shielding effectiveness at Site 3 is so great that the usefulness of high level testing cannot be evaluated without additional data. Thus, a high level pulse test cannot be recommended at this time.

Application of the remainder of the evaluation criteria will not be performed on Technique 3. It can be stated, however, based on previous analyses of high level testing programs, that Technique 3 would rank high in cost and low in practicality and high in interference with site.

#### 5.3.5 Site 3 - Technique 7

Technique 7 consists of low level pulse radiation and POE direct drive. By a low level pulse test is meant testing with a simulator of the Reference 2, we see that the peak E-field from the RES-I at a distance of 100 meters is approximately 5 kV per meter. This is a factor of 10 below a high level pulse such as that radiated by the TEMPS simulator. Although there is no data on the effective shielding of the concrete reinforcing structural steel and the earth overburden for Site 3, the most probable value is 27 dB, based on the SAFCA shielding data. Thus, the signal levels induced in the cabling in Site 3 would be most probably 30 to 50 dB below those signal levels encountered in the Polk City, Florida, and Delta, Utah AUTOVON tests. Thus, the probability of acquiring reasonable data using a low level pulse radiation technique is marginal. Until additional data is available on the effective site shielding at Site 3, Technique 7 utilizing low level pulse radiation could not be recommended. Because of the reduced dynamic range of low level radiation pulse testing, as opposed to low level CW radiation testing, null results in this test would not be particularly meaningful.

However, should the acquisition of additional data indicate that the effective shielding of Site 3 is such that low level pulse induced responses are within the dynamic range of current state-of-the-art data acquisition systems, then a low level pulse radiation test could be used to adequately

map the distribution of energy within the site and to validate models of prediction of electromagnetic response to the various critical interfaces. Should this prove feasible, then Technique 7 using low level radiation and POE direct drive, to extend the POE coupling through threat level, non-linear level, be employed, Technique 7 would be capable of reducing the prediction uncertainties from the current 22 dB to - 9 dB. Hence, the overall uncertainty in using Technique 7 would be equal to  $(9^2 + 3.4^2)^{1/2} = 9.6$  dB. Once again, we must caution however, that this improvement in data accuracy would only be obtained if low level pulse testing should prove to be reasonable based upon additional shielding data.

#### 5.3.5.1 Costs

In a test utilizing a RES simulator, the RES would be required for approximately eight weeks. In 1974, the rental costs for a RES simulator and crew averaged \$10,000 per week. On that basis, an eight week test would cost \$80,000; however, with inflation since 1974 taken into account, a minimum of \$100,000 ought to be anticipated.

The above costs are for simulator rental only. In addition, data acquisition would require the services of one engineer and one technician on-site for the eight week period. In addition, one man-month of engineering and one man-month of technician time for technical publications would be required for test reporting. Thus, 12 man-weeks of engineering and 12 man-weeks of technician time would be required. At \$25 and \$15 per hour, respectively, the total cost would be \$19,200, and the total cost for the low level pulse test could be in the vicinity of \$120,000.

From the above, POE direct drive pulse test at a Site 3 type facility would cost approximately \$24,000.

#### 5.3.5.2 Practicality

The RES simulator is maintained and operated by the Air Force Weapons Laboratory. When in use in an EMP assessment program, the RES is commonly suspended beneath a helicopter. Any test program involving the RES simulator, involves the coordination of at least additional operating entities within the Air Force. Because of these factors, the use of the RES is considered a less practical alternative than CW radiation or POE direct drive. Although Technique 7 is not an extremely impractical or costly program, it is more so than Techniques 2 or 5.

#### 5.3.5.3 Duration of Test

The minimum duration for a reasonable pulse test would be two months. From above we saw that the duration of a POE direct drive test would also be approximately two months. Although the excitation sources for the two types of test are dissimilar there would be enough overlap and data requirements such that both tests could be run concurrently with a time savings of approximately one month. The total on-site test duration for Technique 7 would be approximately three months.

#### 5.3.5.4 Interference with Site

Because of the low level pulsing associated with RES testing, it is extremely improbable that there would be any damage or transient interrupts experienced during a low level pulse test. The only interference with site operations incurred by Technique 7 would be the requirement that site operating personnel be made available to assist data acquisition personnel in locating measurement points.

#### 5.3.6 Site 3 - Technique 8

Technique 8 consists of analysis, CW radiation, POE direct drive (CW), and POE direct drive (P). Technique 8 is identical to Technique 2 with the exception that CW POE direct drive is included. The use of CW radiation

allows direct measurement in the frequency domain of the transfer function from the radiated environment to the point of entry. Potential points of interest in this test include points of entry. When the transfer functions from electromagnetic field to points of interest are determined in the frequency domain they can be inverse Fourier transformed into the time domain and extrapolated to threat. When the addition of POE direct drive pulse testing is done, the transfer functions so determined can be extended into the nonlinear region. When all of this is done, it is difficult to see that the further addition of CW POE direct drive provides any additional confidence in the results of the test.

The inclusion of CW direct drive, although it does not appreciably increase the accuracy of the assessment over Technique 2. It may provide increased efficiency in determining site modeling parameters. This increase deficiency is bought at a cost of requiring additional CW test instrumentation to be provided during the on-site test. This CW direct drive testing would on occasion be done in lieu of CW radiation or direct drive pulse testing for some measurement points.

#### 5.3.6.1 Accuracy

The accuracy of an assessment based on Technique 8 is considered identical to that based on Technique 2.

#### 5.3.6.2 Costs

The costs in terms of manhours for implementing a test based on Technique 8 would be identical to that based on Technique 2 except that some measurements would be performed in the CW mode rather than in the pulse mode. The same test duration and the same personnel requirements are anticipated for both test techniques.

#### 5.3.6.3 Duration of Test

As stated above, the duration for on-site testing utilizing Technique 8 would be identical to Technique 2, that is eight weeks.

#### 5.3.6.4 Practicality

Technique 8 is considered a practical test equivalent to Technique 2.

#### 5.3.6.5 Interference with Site

As stated in Paragraph 5.3.1, any test involving the use of threat level POE excitation has the possibility of transient upset or damage. The only additional interference with site operation would be the requirement for assistance in locating measurement points.

### 5.4 SITE 4

Generic Site 4 is characterized as a single tall structure partially buried. The actual Site 4, shown in elevation view in Figure 2-4, is a 106 foot tall tower of which the bottom 21 feet are buried. It is a blast hardened building with thick reinforced concrete walls. Some sites in Class 4 have structural steel liners installed for blast hardening purposes. Although these wall liners were not installed with electromagnetic shielding in mind, they will provide some shielding but of an unpredictable nature. A site with such liners may react as a single tall open-ended cylinder or as a series of stacked short squat open-ended cylinders. It is not known whether or not the actual Site 4 has the steel liners. Because of the foregoing the amount of shielding provided by the structure to the inside electronics is completely unspecified. Site 4 is a cylindrical shaped tower. Because of this, it is amenable to analytic analysis of the shielding.

Site 4 has very few penetrations or points of entry. There are no communication cables. The primary points of entry are the antennas on the roof, the tower itself, and the utility penetrations.

#### 5.4.1 Site 4 - Technique 2

Technique 2 consists of Analysis, CW Radiation, and POE Direct Drive (P). At this time the shielding effectiveness of the tower walls at Site 4 is completely unspecified.

#### 5.4.1.1 Analysis

It is assumed that a site survey conducted by a group of experienced electromagnetic pulse survey engineers, would provide sufficient detail information such that an analytic assessment of quality comparable to that performed on other sites could be accomplished.

Therefore, it is assumed that an abbreviated style analytic assessment of Site 4 could be accomplished with an accuracy of 25 dB.

#### 5.4.1.2 CW Radiation

In a site whose electromagnetic shielding is completely unknown, a preliminary CW radiation test is most applicable. Such a test would quickly determine the effect of electromagnetic shielding and allow direct measurement of the transfer functions of the more significant penetrations, and provide increased confidence in the modeling parameters chosen by the analyst. Should it be determined that Site 4 has an effective electromagnetic shield provided by steel liners, then a CW test would remove the internal field coupling portion of the problem from the analyst task making his predictions easier and more accurate. In such a case no results would be significant. Should the electromagnetic shielding provided by the liner prove to be negligible at least in some areas or for some frequencies then the CW test would provide detailed modeling information. In either case the CW test would increase the confidence in the analytic assessment from 25 to 15 dB. The use of the CW test is particularly appropriate for Site 4 because of its vertical geometry. The common method of providing radiated CW is with the use of vertically polarized monopoles. This would increase the effective dynamic range of the field coupling to the structure.

#### 5.4.1.3 POE Direct Drive (Pulse)

The POE direct drive test minimizes the uncertainties in the coupling model from the point of entry to the circuit level. Thus, the remaining uncertainty is that associated with prediction at the point of entry and the uncertainty associated with the threshold of the circuit. The uncertainty in

the predicted field levels at the point of entry is typically 9 dB. The error associated with the thresholds is typically 5 dB. The total error predictions based on POE direct drive tests is reduced from 22 to 10 dB.

#### 5.4.1.4 Technique 2 - Overall Accuracy

For a site which maximizes coupling of vertically polarized fields, which has low electromagnetic shielding, and which has a limited number of points of entry the combination of CW radiation with POE direct drive is particularly appropriate. The CW radiation test would determine the transfer functions linking the radiated field directly to the circuits of interest, and the POE direct drive test would remove any uncertainties associated with nonlinear behavior. It is difficult to quantitatively assess the impact of this combination but a reasonable engineering judgement of the accuracy of this technique is that a combined assessment statement would be made with an accuracy of approximately 10 dB.

#### 5.4.1.5 Cost

Because of its relative simplicity, both geometrically and in terms of numbers of POEs, an abbreviated style analytic assessment would be appropriate for Site 4. Such an assessment could be accomplished for approximately \$25,000 to \$35,000.

A CW radiation test of a site such as Site 4 would require one man month of an engineer and one man month of a technician on-site to set up the equipment and complete the test. In addition, two weeks of engineering and two weeks of technician assistance from technical publications would be required to prepare a report. Thus, a total of six manweeks of engineering and six manweeks of technician time would be required. The total cost of such a test would be \$9,600. This cost would not include any pretest analysis or post test data reduction or analysis.

The cost of a POE Direct Drive (P) test would be similar to that of a CW radiation test approximately one month on-site two weeks of technical reporting would be required. Total cost for this test would again be \$9,600.

Because both the CW radiation test and the direct drive pulse test have already been reduced to their absolute minimum of one month on-site, no synergistic effects would be anticipated in conducting both tests concurrently. Each test would have to be completed in its allotted time of one month. The total cost then would be approximately \$20,000.

5.4.1.6 Duration

The total duration of on-site testing would be two months, one each for CW and direct drive testing.

5.4.1.7 Practicality

The combination of CW radiation and POE direct drive is an extremely practical test to run. This test program would involve a minimum number of agencies mainly the site user, the test sponsor and the test contractor(s). Both the hardware and the expertise for such tests exist within several government agencies and several civilian contractors.

5.4.1.8 Interference with Site

Interference with site operations during a test program utilizing Technique 2 would be minimal. During the two month on-site period of testing, site operating personnel would be required to assist in data acquisition. During POE direct drive at threat level pulses would entail a moderate risk of transient site interrupt or possible damage. No other form of interference during this technique is to be anticipated.

5.4.2 Site 4 - Technique 3

Technique 3 consists of Analysis, High Level Pulse Radiation, and POE Direct Drive (P). The high level pulse simulator most appropriate for testing a site such as Site 4 is TEMPS. The SIEGE simulator would only be useful for a completely buried facility. Because the TEMPS simulator radiates primarily horizontally polarized components, while the tower at Site 4 would be excited primarily by vertically polarized components, and because the effective electromagnetic shielding of Site 4 is completely unknown, it is impossible at this time (without further test or evaluation) to quantitatively determine the advantages of high level pulse testing. Because of this lack of

quantitative information it is not sound to make a positive recommendation for any technique involving the use of such expensive simulation as a high level pulse test. It would seem, therefore, that both Technique 3 and Technique 6 should not be recommended for implementation at Site 4 at this time. Should additional test data or additional analytic evaluation indicate that sufficient coupling between the horizontal polarized fields of the simulator and the tower would exist to generate meaningful data then this recommendation should be re-evaluated.

Because of this, Techniques 3 and 6 will be eliminated from further consideration in this Section.

#### 5.4.3 Site 4 - Technique 4

Technique 4 consists of analysis and POE Direct Drive (P).

##### 5.4.3.1 Accuracy

The analytic assessment accuracy for this site would as previously determined be 25 dB. A POE direct drive test in the pulse domain would generate directly transfer functions from the point of entry to the circuits of interest in the threat level nonlinear area. Hence, a POE direct drive would enhance the accuracy of the prediction from 25 dB to 15 dB. Cost from above of POE direct drive test of a relatively simple site such as Site 4 would be approximately \$9,600.

##### 5.4.3.2 Cost

Cost from above of POE direct drive test of a relatively simple site such as Site 4 would be approximately \$9,600.

##### 5.4.3.3 Duration

As stated before, such a test would require one month on-site test time.

##### 5.4.3.4 Practicality

This would be an extremely practical technique to implement inasmuch as the hardware, the expertise for a POE direct drive test exist within several agencies.

#### 5.4.3.5 Interference with Facility

During any high level direct drive test possibility of occasional transient interrupt or damage exists. In addition, operating personnel would be required to assist the data acquisition engineers in locating measurement points.

#### 5.4.4 Site 4 - Technique 7

Technique 7 consists of Analysis, Low Level Pulse Radiation, and POE Direct Drive (P). The low level pulse technique evaluated for use on Site 4 involves the use of the vertically polarized airborne RES pulser. The vertically polarized RES was chosen because of the vertical geometry of Site 4.

##### 5.4.4.1 Accuracy of the Data

A test program utilizing both pulse radiation and POE direct drive would result in an overall assessment with accuracies of the order of 10 to 12 dB.

##### 5.4.4.2 Cost

Total cost for the RES simulator averages \$10,000 per week. For a relatively simple site such as Site 4, it is estimated that a two month test period would be adequate. The rental cost for the RES would be approximately \$80,000. In addition, two data acquisition engineers and technicians would be required. After the test program, approximately one month of engineering and one month technician time would be required for preparation of a test report. A total cost for the Low Level Radiation test would then be in the vicinity of \$125,000. The cost for the analytic assessment of Site 4 would be between \$25,000 and \$35,000. Total cost for a POE direct drive would be \$9,600. Adding the component costs together results in a total assessment cost of between \$160,000 and \$170,000.

##### 5.4.4.3 Duration of Test

Total test time would be four months; there would be little or no time savings brought about by the common data requirements because of the already compressed schedule.

5.4.4.4 Practicality

This test technique ranks low in practicality inasmuch as many agencies are required to support a RES type test. The RES simulator is in the custody of the Air Force Weapons Lab, and a helicopter from the Air Force is required. This introduces two additional Air Force agencies

5.4.4.5 Interference with Site

The cooperation of the site personnel would be required to locate measurement points for both the low level pulse test and POE test. During the POE test, as in any high level test, possibility of transient interrupts and damage exists.

5.4.5 Site 4 - Technique 8

*Technique consists of analysis, CW radiation, POE Direct Drive (Pulse) and POE Direct Drive (CW).* As indicated earlier in the evaluation of Site 3, Technique 8 is considered identical in effectiveness, accuracy, practicality, and duration to Technique 2.

SECTION 6  
RESULTS

Numerical results of the preceding analyses are presented in Figures 6-1 through 6-4.

OZ MCD-10M1	EVAL. CRITERIA	ACCURACY OF TEST DATA (db)							COSTS (\$1,000.00)	DURATION OF TEST (MONTHS)	PRACTICALITY (RELATIVE ARBITRARY SCALE)	INTERFERENCE WITH SITE
		POE (P)		HIGH LEVEL PULSE RADIATION	LOW LEVEL PULSE RADIATION	CW RADIATION	SCALE MODELING	SUB-SYSTEM TESTING				
		POE (CW)	POE (P)									
1						4	3.5	18	130 to 204	6	High	0
2	2.5							15	105 to 355	4	High	Med; Potential Interrupts and Damage I&D
3	2.5			Up to 40 (1)				15	1,000	6-8	Low	Large; facility construction Potential I&D
4	2.5							15	105 to 355	3-4	High	Med; Potential I&D
5							3	20	117 to 189	6	High	Low; Assistance from site
6				Up to 40 (1)				25	500	3	Low	Large; facility construction Potential I&D

Figure 6-1. Site 1 Results

TECHNIQUE #1 ANALYSIS; SCALE MODELING SUBSYSTEM TEST  
 TECHNIQUE #2 ANALYSIS; CW RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #3 ANALYSIS; HIGH LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #4 ANALYSIS; POE DIRECT DRIVE (P)  
 TECHNIQUE #5 ANALYSIS; CW RADIATION; SUBSYSTEM TEST  
 TECHNIQUE #6 ANALYSIS; HIGH LEVEL PULSE RADIATION

(1) Based on poor S/N at most points

OZ MCD-10M1	EVAL. CRI-TERIA	ACCURACY OF TEST DATA (db)										DURATION OF TEST (MONTHS)	PRACTICALITY (RELATIVE ARBITRARY SCALE)	INTERFERENCE WITH SITE
		POE (P)	POE (CW)	HIGH LEVEL PULSE RADIATION	LOW LEVEL PULSE RADIATION	CW RADIATION	SCALE MODELING	SUB-SYSTEM TESTING	ACCURACY OF ASSESSMENT AT THREAT (db)		COSTS (\$1,000.00)			
2	2.5					Up to 10 (1)			13	46 to 56	3	High	Med; Potential Interrupts and Damage I&D	
3	2.5	2.5							10-12	600	6	Low	Large; facility construction Potential I&D	
5						1		3.5	15	59 to 64	4	High	Low; Assistance from site	
6			2.5						?	500	6	Low	Large	
7	2.5			40 (1) (2)										
8	2.5	1.5				1			13	46 to 56	3	High	Med; Potential Interrupts and Damage I&D	

Figure 6-2. Site 2 Results

TECHNIQUE #2 ANALYSIS: CW RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #3 ANALYSIS: HIGH LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #5 ANALYSIS: CW RADIATION; SUBSYSTEM ("BLACK BOX") TESTING  
 TECHNIQUE #6 ANALYSIS: HIGH LEVEL PULSE  
 TECHNIQUE #7 ANALYSIS: LOW-LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #8 ANALYSIS: CW RADIATION; POE DIRECT DRIVE (CW); POE DIRECT DRIVE (P)  
 (1) Based on poor S/N (2) Considered unacceptably high

QZ MCD-10M4	EVAL. CRI-TERIA	ACCURACY OF TEST DATA (db)										DURATION OF TEST (MONTHS)	PRACTICALITY (RELATIVE ARBITRARY SCALE)	INTERFERENCE WITH SITE
		POE (P)	POE (CW)	HIGH LEVEL PULSE RADIATION	LOW LEVEL PULSE RADIATION	CW RADIATION	SCALE MODELING	SUB-SYSTEM TESTING	ACCURACY OF ASSESSMENT AT THREAT (db)		COSTS (\$1,000.00)			
2	2.5					1			10	92 to 119	3	High	Med; Potential Interrupts and Damage I&D	
3	2.5		Un-known						15	500 to 600	6	Low	High; facility construction potential I&D	
5						1		3.5	12-13	86 to 126	3	High	Low; Assistance from site	
6				?					?	High	3	Low	Large	
7	2.5								15	194 to 219	3	Low	Med; Potential Interrupts and Damage I&D	
8	2.5	1				1			10	92 to 119	3	High	Med; Potential Interrupts and Damage I&D	

Figure 6-3. Site 3 Results

TECHNIQUE #2 ANALYSIS: CW RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #3 ANALYSIS: HIGH LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #5 ANALYSIS: CW RADIATION; SUBSYSTEM ("BLACK BOX") TESTING  
 TECHNIQUE #6 ANALYSIS: HIGH LEVEL PULSE  
 TECHNIQUE #7 ANALYSIS: LOW-LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #8 ANALYSIS: CW RADIATION; POE DIRECT DRIVE (CW); POE DIRECT DRIVE (P)

OZ MCD-10M1	EVAL. CRI-TERIA	ACCURACY OF TEST DATA (db)								ACCU- RACY OF ASSESSMENT AT THREAT (db)	COSTS (\$1,000,000)	DURATION OF TEST (MONTHS)	PRACTICALITY (RELATIVE ARBITRARY SCALE)	INTERFERENCE WITH SITE
		POE (P)	POE (CW)	HIGH LEVEL PULSE RADIATION	LOW LEVEL PULSE RADIATION	CW RADIATION	SCALE MODELING	SUB-SYSTEM TESTING						
2	2.5					1			10	45 to 55	2	High	Med; Potential Interrupts and Damage I&D	
3	Not Recommended, Not Evaluated													
4	2.5								15	35 to 45	1	High	Med; Potential Interrupts and Damage I&D	
6	Not Recommended, Not Evaluated													
7	2.5			2.5					10-12	160 to 170	4	Low	Med; Potential Interrupts and Damage I&D	
8	2.5	1				1			10	45 to 50	2	High	Med; Potential Interrupts and Damage I&D	

Figure 6-4. Site 4 Results

- TECHNIQUE #2 ANALYSIS; CW RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #3 ANALYSIS; HIGH-LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #4 ANALYSIS; POE DIRECT DRIVE (P)  
 TECHNIQUE #6 ANALYSIS; HIGH-LEVEL PULSE RADIATION  
 TECHNIQUE #7 ANALYSIS; LOW-LEVEL PULSE RADIATION; POE DIRECT DRIVE (P)  
 TECHNIQUE #8 ANALYSIS; CW RADIATION; POE DIRECT DRIVE (DW); POE DIRECT DRIVE (P)

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